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Aeronautics and Space Report of the President

1989–1990 Activities

1991
National Aeronautics
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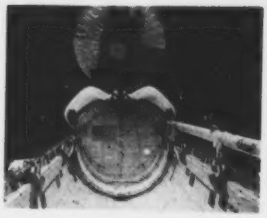

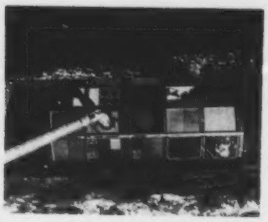

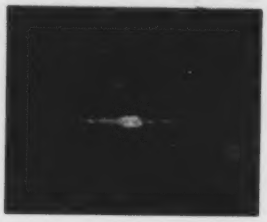

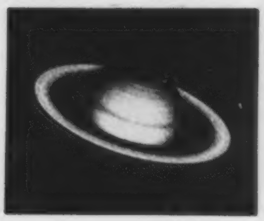

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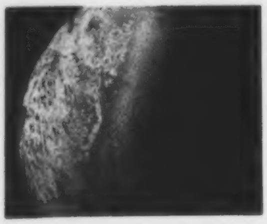

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Executive Summary

Note: only this volume reports on combined calendar year 1989 and fiscal year 1990 activities. Reports published hereafter in this series will be based on annual fiscal year activities.

This executive summary briefly describes the aeronautics and space accomplishments of each of the 14 participating Government organizations for calendar year (CY) 1989 and fiscal year (FY) 1990. The remaining chapters, then, will provide more detail on each organization's aeronautics and space activities for these years.

National Aeronautics and Space Administration

Human Space Flight

Major efforts in the National Aeronautics and Space Administration's (NASA) human space flight program focused on developing space transportation capabilities, carrying out space flight operations, and sending people to work in space. NASA successfully completed eight shuttle missions in CY 1989 and FY 1990. These missions involved deploying a Tracking and Data Relay Satellite, the Magellan Venus probe, the Galileo Jupiter probe, Syncom IV (a Navy communications satellite), the Hubble Space Telescope, the retrieval of the Long Duration Exposure Facility, and three classified Department of Defense missions.

Another significant activity of 1989 was the naming of the new shuttle orbiter. The name "Endeavour," submitted by school children in the orbiter-naming contest, was selected for Orbiter Vehicle 105. Endeavour is scheduled to be completed and delivered to NASA in 1991.

A major reassessment of the space station budget occurred in 1989, prompted by a shortfall in the Congressional appropriation for FY 1990. During this review, some management and budget changes were implemented, and some capabilities were deferred until later in the program. However, the goal for the launch of the first element of the station continued to be March 1995.

In FY 1990 the Space Station program made considerable headway on preliminary design of hardware elements such as the habitation module, the U.S. laboratory, the truss structure, the mobile transporter, power and propulsion systems, and the Attached Payloads Accommodation Equipment. NASA extensively tested hardware for the environmental control system and selected technologies for use in the air and water recovery loops. The program also refined the requirements for building and implementing all the ground infrastructure essential to operate, use, and support the station over its projected 30-year life. Other major program accomplishments included reducing weight, power, and extravehicular activity requirements associated with the current design.

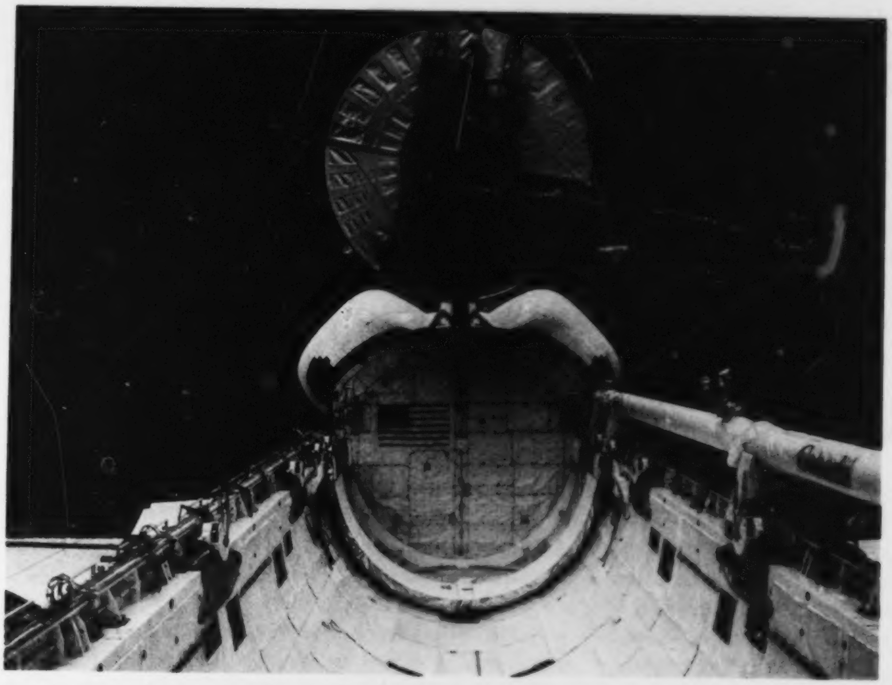
In addition, NASA continued to work closely with its international space station partners in Europe, Canada, and Japan. Several coordinated studies and reviews were completed, and NASA and the partners continued to work together on the program-level Integrated System Preliminary Design Review expected to conclude near the end of 1990. All four partners agreed on an International Standard Payload Rack that would facilitate commonality and payload interchangeability.

Finally, NASA conducted advanced systems studies and planning efforts to identify preliminary reference configurations for potential evolution of the station. This included analysis of possible requirements to support the Space Exploration Initiative (SEI).

The SEI was approved by President Bush on February 16, 1990 as a far-reaching program to return to the moon and press on toward exploration of Mars. On May 11, 1990, the President established a goal for human beings on Mars by 2019. In response to this challenge, on May 31, 1990, NASA established the SEI Outreach Program.

Unmanned Expendable Launch Vehicles

There were 28 unmanned expendable launch vehicle (ELV) launches during the nearly two-year period of this report. Four spacecraft, originally assigned for launch from the shuttle, were reassigned to ELVs as a part of the mixed fleet strategy developed to assure access to space. All four of these spacecraft—the Roentgen satellite, the Combined Release and Radiation Effects satellite, the Extreme Ultraviolet Explorer, and the Mars Observer—were launched or were under contract to launch on ELVs. Also, NASA, in its role as "service provider," allowed access to NASA facilities at direct cost to the commercial launch industry.



The Syncom IV-5 Navy communications satellite leaving the cargo bay of STS-32, Columbia, January 10, 1990.

NASA also sought to expand cooperative efforts with U.S. industry to develop space and accelerate the commercial application of space technologies. During 1989 and FY 1990, NASA made special progress in defining an overall program of commercial space development. To this end, its Office of Commercial Programs' Centers for the Commercial Development of Space engaged significant numbers of U.S. firms in commercial space development. New technologies, products, supporting transportation and infrastructure systems, and business enterprises have emerged as a result of these cooperative efforts. The challenge to produce a program that develops commercial space markets, low-cost commercial space transportation systems, and commercial space infrastructure that strengthens U.S. industrial competitiveness is being addressed through these efforts.

Space Science and Applications

NASA has continued its ongoing efforts to support future space science missions in the solar system. Calendar year 1989 heralded the beginning of a burst of new activity. In May, the shuttle deployed the Magellan Venus probe, where it arrived in August 1990 and began a multi-year mission mapping its surface. In August 1989, after traveling 4.4 billion miles for 12 years, Voyager 2 flew past the planet Neptune exciting the world with its many discoveries, such as active volcanoes on its moon Triton. In September 1989, the importance of a small mission was demonstrated when an instrument aboard a sounding rocket captured the most detailed series of solar flare images ever obtained. In October 1989, the Galileo space probe began its circuitous journey to Jupiter after launch from the shuttle. Finally, in November 1989, the Cosmic Background Explorer was launched carrying instruments to measure the radiation from the "Big Bang," the primordial explosion thought to have marked the creation of the universe.

NASA also cooperated in search-and-rescue and disaster medical aid in 1989. COSPAS-SARSAT, a satellite-based search-and-rescue system, has saved more than 1,400 lives in total, and the Telemedicine Spacebridge has provided medical advice to earthquake victims of Soviet Armenia and later to victims of other Soviet disasters.

The ambitious achievements of 1989 were continued through FY 1990 with a full range of scientific disciplines that included the launches of various satellites including the Pegsat, the Hubble Space Telescope, the Roentgen satellite, and the Combined Release and Radiation Effects satellite. A new start was approved for CRAF-Cassini, a program that will provide unprecedented information on the origin of our solar system. CRAF (the Comet Rendezvous/Asteroid Flyby) will analyze for the first time the solid material of which a comet is made. Cassini, after a four-year study of Saturn, will measure the atmosphere of its largest moon, Titan.

Space Communications Operations

In 1989, the Tracking and Data Relay Satellite System (TDRSS) became fully operational in geosynchronous orbit, providing communications support to spacecraft in low-Earth-orbit. This network provides communication and tracking for over 85 percent of each spacecraft orbit around Earth, a major advancement in space communications. With the previous ground-tracking network, coverage was limited to only about 15 percent of a spacecraft orbit. This event brought to reality the long-awaited transition from a ground-based tracking network to a space-based tracking capability for low-Earth-orbit missions. The operational Space Network allowed NASA to close or transfer to other agencies the four ground stations. In January 1990, the Second TDRSS Ground Terminal was dedicated in New Mexico. The new facility provides backup to the first ground terminal and adds the capability to operate future TDRSS satellites when demand increases.

The Ground Networks of NASA included the Spaceflight Tracking and Data Network, the Deep Space Network, the Aeronautics, Balloon, and Sounding Rocket programs. All were effectively utilized in 1989 and 1990. They provided tracking and data acquisition support services to all NASA missions for vehicles in high-Earth orbit, in deep space, and for sub-orbital flights. In August 1989, for example, the Deep Space Network performed a nearly flawless operation during the Voyager 2 encounter with Neptune, which was the culmination of a 12-year mission. The Deep Space Network was augmented by non-NASA facilities in Australia, Japan, and New Mexico for this encounter. In 1990, the Ground Networks also provided launch and landing support for shuttle missions and tracking and data acquisition support for Magellan, Galileo, and Ulysses. Foreign missions were also supported to collect data from Earth and the moon.

Space Research and Technology

The primary goal of the Space Research and Technology program is to develop technologies that enhance or enable our space missions and thereby support U.S. leadership in space through a broad-based research program. This program has continued in a quiet but efficient manner for many years. It serves to advance technology at the concept, subsystem, and system level; to develop technical strengths in the engineering disciplines within NASA, industry, and academia; and to perform critical flight experiments where testing in space is necessary.

The Space Research and Technology program is structured into five technology thrusts related to Space Science, Space Transportation, Space Station, Exploration, and Breakthrough Technologies. In addition, a key element of the Space Research and Technology program is developing and sustaining a strong partnership with the university community through the University Space Research program. This is an integral part of the strategy to strengthen the space research and technology capabilities of the Nation. In 1989 and 1990, significant progress was accomplished in many key disciplines such as propulsion, power, information and controls, materials and structures, aerothermodynamics, and space flight experiments. This progress will contribute to achieving our future objectives in space science, space transportation, space station, and exploration.

Aeronautics Research and Technology

NASA's aeronautics program implementation, in close coordination with industry, the Federal Aviation Administration, the Department of Defense, and other Government agencies, continued to be accomplished during 1989 and 1990 through pursuit of six key thrusts. The first thrust, subsonic transport, is focused on developing technology that will increase the productivity, affordability, and competitiveness of U.S. commercial transport aircraft. The second thrust, high-speed transportation, is based on resolving critical environmental issues and establishing the technology for economical, high-speed air transportation. The research program's goals focus on resolving problems with atmospheric effects, airport community noise, and sonic booms. The third of these, the high-performance aircraft research program, is structured to develop technologies having important military applications. The fourth, the hypersonics and transatmospheric research program, is an integrated multi-disciplinary effort aimed at building fundamental technical understanding of the controlling physical phenomena of airbreathing hypersonic vehicles. Research has been focused on development of technologies required for hypersonic cruise in the atmosphere, single-stage-to-orbit using airbreathing primary propulsion, and horizontal takeoff and landing. The fifth, the fundamental technology base thrust, has been pursuing revolutionary advances in the basic sciences necessary for the design and operation of next-generation aeronautical systems. And finally, NASA has embarked on a sixth key thrust, a five-year revitalization program for the unique, high-value experimental wind tunnels, some now more than 30 years old.

Department of Defense

Calendar year 1989 and fiscal year 1990 could best be characterized as a period of sustained emphasis for the Department of Defense (DOD) in the space area. Notable space achievements for the agency included the Defense Advanced Research Projects Agency (DARPA) sponsored, commercially developed programs culminating in the first Pegasus launch on April 5, 1990 and the first Titan IV successful launch in June 1990.

DOD space launches for the two-year period revolved around orbiting a number of communications and navigation satellites, including the Fleet Satellite Communication System (FLTSATCOM) FLTSAT 8, and the Defense Satellite Communication System (DSCS) II and III. In addition, DARPA launched its first-generation LightSat communication satellite aboard a Scout booster in May 1990. The first five operational Global Positioning System (GPS) Block IIR satellites were launched during the same year and by December approximately 4,000 DOD GPS receivers were in use or on order to provide real-time flight-following capability for DOD aircraft and ships.

Furthermore, during 1989 the Under Secretary of Defense for Acquisition elected to proceed with an inter-Service program to develop a ground-based kinetic energy anti-satellite capability. The Army was named as the lead Service in this effort. One of the critical DOD space-oriented activities of 1989 and FY 1990 was the development of new technologies for assured defense from nuclear attack. The Strategic Defense Initiative program proceeded with a record number of successful major experiments and tests.

In the aeronautics area, flight tests of the B-2 Advanced Technology Bomber began in July 1989 and it flew 16 test missions for a total of over 67 hours with no major problems. Additional acquisition efforts for the C-17 transport, the advanced tactical fighter, the small intercontinental ballistic missile, and several other programs continued during the two-year period.

Of critical importance, the National Aero-Space Plane program proceeded and, after review by the National Space Council, was reaffirmed by the President in July 1989. The X-29 Advanced Technology Demonstrator testing also continued successfully, as did flight testing of the F-15 Short-Takeoff and-Landing/Maneuver Technology Demonstrator.

Department of Commerce

The Department of Commerce (DOC) has four components involved in space activities. As the Earth systems agency, the National Oceanic and Atmospheric Administration (NOAA), through its National Environmental Satellite, Data, and Information Service, is the largest space arm of DOC. NOAA is responsible for both the operational polar orbiting and geostationary satellites and will have several instruments on NASA's Earth Observing System. As operational satellite-derived products are refined and developed, they are used by the country's weather and climate services—Government, academic, and private. Satellite data were used in operational forecasting and in studies of severe weather and tropical storms. Expansion continued in the distribution of satellite information—from the Advanced Very High Resolution Radiometer, from the Visible and Infrared Spin-Scan Radiometer Atmospheric Sounder, and by using GOES-Tap (a program enabling users to acquire high-quality Geostationary Operational Environmental Satellite imagery over telephone data circuits). Studies continued on ozone, cloud occurrence, and snow cover—factors critical to our study of climate change. A new operational program was CoastWatch—NOAA's coastal land and water program which obtains environmental information on coastal physical oceanography and meteorology and provides environmental alerts to coastal communities. NOAA initiated projects to acquire, archive, and disseminate data packages needed in monitoring the global climate and its change. In international activities, two operational programs continued—COSPAS/SARSAT and a revitalized PEACESAT (Pan-Pacific Educational and Cultural Experiments by Satellite).

The newest space activities component of DOC is the Office of Space Commerce, which was formally established in 1988. It is the Department's principal unit for the coordination of commercial space-related issues, programs, and initiatives.

Commerce's National Telecommunications and Information Administration (NTIA) continued its presence on international committees and working groups, as well as working with foreign satellite consortia. NTIA continued in the World Administrative Radio Conference in 1989, participating in an assessment of the 1988 U.S. position paper of importance to U.S. space interests. Planning continued for the experiments to be conducted for the Advanced Communications Technology Satellite—under development by NASA. The deployment of mobile millimeter wave measurement systems continued for use in Earth-spacecraft communications.

Finally, Commerce's National Institute of Standards and Technology, formerly the National Bureau of Standards, participated in space programs support including the spectrograph calibration on the Hubble Space Telescope, resolution of unexpected satellite technical development problems, and numerous other calibration and standardization studies. Certain high-performance aerospace materials, that is, metallic substances, heat exchangers, and advanced ceramics were under study. In space science research, several spectroscopic studies and analyses of stellar features continue. Research in gravitational and tectonic areas also is going on. In atmospheric research, the following are under study: ozone depletion, the greenhouse effect of other gases, and methods of investigating other chemical atmospheric constituents.

Department of Energy

The U.S. Department of Energy (DOE) provides nuclear power sources for NASA space missions. Such power units have enabled spectacular missions like the Voyager flyby of Neptune and the Apollo lunar-surface scientific work. A summary of 1989 and 1990 progress follows.

The Radioisotope Thermoelectric Generator (RTG) program develops and builds devices that directly convert heat from the fuel Plutonium-238 into electricity. Progress included the successful launch of the RTG-powered Galileo and Ulysses spacecraft; continued life testing of over 49,000 hours of a qualification RTG unit; and various actions intended to upgrade and maintain RTG production facilities. In the Turbine Energy Conversion System program, designed to achieve 18 to 25 percent energy conversion efficiencies from Plutonium-238 fuel, progress included the following: selection of the optimized design parameter; completion of a preliminary turbine alternator compressor design; testing of various subcomponents; and examination of potential missions.

The purpose of the SP-100 Space Reactor program is to develop, demonstrate, and make available to NASA and DOD space reactor power in the tens to hundreds of kilowatts-electric power range. Progress included completion of major system design activities; manufacturing of 75 percent of the ground-test reactor fuel; an increase in power density of nearly tenfold over present thermoelectric technology; a demonstration that the reactor vessel and internal structures could be fabricated; and fabrication of a more prototypic thermoelectric cell.

The Thermionic Fuel Element Verification program is intended to resolve issues enabling thermionics to be a viable technology for future space reactor systems. Activities consisted of lifetime component testing in accelerated and real-time environments.

An additional DOE responsibility is providing satellite equipment for continuous monitoring of nuclear detonations anywhere within Earth's atmosphere or neighboring interplanetary space. This program supports treaty verification, intelligence gathering, and military goals.

Department of the Interior

The Department of the Interior uses data acquired by satellite and aircraft sensors to inventory natural resources and monitor changes on lands under its management and maintains an active program of research and technique development in remote sensing. In 1989 and 1990, the Department continued to archive, process, and distribute Landsat and Advanced Very High Resolution

Radiometer satellite data. The National Aerial Photography and Side-Looking Airborne Radar programs acquired data over priority U.S. areas. Major land-management applications of remote sensing included land-use and land-cover mapping (especially in Alaska), vegetation mapping, wildfire mapping and monitoring, irrigated lands inventory, and wetlands mapping and inventory. Hydrologic applications included snow-cover mapping and monitoring and modeling of reservoir surface-water parameters. Oceanographic applications included monitoring of marine-mammal migration. Geologic applications included digital image processing for geologic mapping and mineral resource assessment in semiarid terrains, surface coal-mine monitoring, landslide hazard assessment, and volcano monitoring. Planetary studies included data archiving, the Voyager flyby of Neptune's moon, Triton, and observation of Earth-approaching asteroids. Cartographic applications included satellite image mapping, digital image-processing research, and studies using Global Positioning Systems. Global change research included studies of sea ice, snow, ice sheets, and glaciers, and studies of detailed coastal morphology related to sea-level change. Work began to develop information systems to improve access to land-related, remotely sensed, and Earth-science data for global-change research, and development of techniques to produce and distribute regional, continental, and global land data sets. International programs were carried out in Africa, the Middle East, Latin America, Iceland, and Antarctica.

Department of Agriculture

In 1989, space-related activities of the U.S. Department of Agriculture included basic research on development of plant-growing systems that could be adapted to manned space vehicles and remote-sensing applications research. Although focused on finding optimum growing conditions given certain environmental stress factors, the basic research on development of plant-growing systems can be directly related to plant growth and productivity in the closed environment of a spacecraft. Remote-sensing applications research included demonstrations of the use of digital Landsat data for monitoring sediment in lakes and reservoirs and for monitoring the destruction of defoliated cotton stalks for bollworm control. An airborne laser profiler was used to determine soil loss caused by erosion.

Federal Communications Commission

Communications Satellites

The Federal Communications Commission granted authority to the Communications Satellite Corporation (Comsat) to participate in the launch of the final INTELSAT V series satellite and the first three INTELSAT VI series satellites. The International Telecommunications Satellites Organization's second INTELSAT VI launch failed to achieve geostationary orbit. The United States and the United Kingdom completed Article XIV(d) consultation with INTELSAT for two more U.S. international satellites to be used by the Orion Satellite Corporation for service between the United States and the United Kingdom.

In 1989, the Commission decided that the public interest requires that the International Maritime Satellite Organization (INMARSAT) aeronautical mobile-satellite services be made available to users in the United States and that these services are best suited for aircraft that are in international flight. The Commission also permitted Comsat to be the U.S. provider of INMARSAT aeronautical space segment capacity. INMARSAT issued a Request for Proposals for a third-generation satellite system. The specifications for this system include spot beams and the capability to operate within the full maritime and aeronautical mobile-satellite spectrum. In mid-1990, the INMARSAT Council authorized the Director General to negotiate and award a contract by the end of 1990 for the purchase of three or four INMARSAT III satellites.

In 1989, the Commission authorized the American Mobile Satellite Corporation to construct, launch, and operate three satellites in the mobile satellite service, which is expected to be implemented in 1993 and 1994, to provide a variety of domestic land, aeronautical, and maritime mobile-satellite services.

Geostar Positioning Corporation commenced two-way start-up radiodetermination satellite service in the United States in 1989. The Commission also authorized Qualcomm Corporation to construct and operate a two-way mobile data communications network to provide a variety of data services between a customer's operation center and its mobile users.

Department of Transportation

Federal Aviation Administration

Pursuing its mission to promote the efficiency and safety of civil aviation, Transportation's Federal Aviation Administration (FAA) engaged in a broad range of research and development. One major objective was the continued modernization of the Nation's system of air navigation and air traffic control. For example, production began for the first segment of the Advanced Automation System, which will eventually provide air traffic controllers with new workstations and greatly expanded capabilities. Another noteworthy milestone was the New York Terminal Approach Control facility's attainment of the ability to track 1,700 aircraft simultaneously as part of an ongoing upgrade. To supplement such improvements to its ground facilities, the FAA pressed ahead with the airborne Traffic Alert and Collision Avoidance System.

The agency's efforts to enhance airport capacity included operational demonstrations of Precision Runway Monitor prototypes using radar with high update rates. Aeronautical Data Link applications played an important role in airport demonstrations of an innovative clearance procedure for speeding departing flights, and work proceeded on new automated techniques for managing aircraft in the air and on runways and taxiways. Among its many weather-related programs, the agency conducted operational evaluations of two Terminal Doppler Weather Radars and placed its first Automated Weather Observing System in service.

FAA published a National Aging Aircraft Research Program Plan, began work on a new system to rapidly collect and disseminate airworthiness data to worldwide users of U.S. aircraft, and pursued a vigorous program of human factors research. Steps to strengthen aviation security included deployment of the advanced Thermal Neutron Analysis system for detecting explosives in baggage. Other safety projects yielded useful data on such varied issues as crashworthiness, alternative fuels, bird ingestion by jet engines, and evacuation of smoke from in-flight fires. FAA also engaged in research activities to foster civil use of rotorcraft and tiltrotors.

Commercial Space Transportation

This period marked a turning point for the Department of Transportation's Office of Commercial Space Transportation and the U.S. commercial launch industry. The first suborbital and orbital U.S. commercial launches licensed under the Commercial Space Launch Act took place. On March 29, 1989, Space Services Inc. of America conducted a suborbital launch from the White Sands Missile Range in New Mexico. On August 27, 1989, a McDonnell Douglas Delta rocket lifted off from Cape Canaveral carrying a British communications satellite. A total of 10 successful launches took place during fiscal years 1989-1990.

Other important highlights for the year include the issuance of 14 launch licenses, completion of a study of the scheduling practices and launch operations at existing U.S. ranges, and completion of a preliminary safety review of two proposed commercial launch sites in Hawaii. In addition, the Office of Commercial Space Transportation continues to monitor developments in the world commercial market and advocates U.S. policies to strengthen the competitive position of U.S. launch firms in the world market. The Office of Commercial Space Transportation also issued six Commercial Launch Manifests. The latest launch manifest, issued in July 1990, lists a total of 35 commercial launch contracts.

Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA), through its Environmental Monitoring Systems Laboratory in Las Vegas, NV, routinely conducts research and technical support using remote sensing as part of an overall environmental monitoring program. Large-scale aerial photography is collected and interpreted to support the provisions of the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability Act; medium-scale photography is collected and interpreted to support non-point-source pollution studies, wetlands protection, coastal zone studies, and forest-ecosystem decline caused by acid deposition; and high altitude photography is interpreted for broad area studies in the coastal zone and to contribute land-use and land-cover information in risk-assessment studies. Airborne and satellite multispectral scanner data are collected and interpreted to support water-quality, non-pointsource pollution, hazardous-waste, and critical-habitat investigations. Airborne laser systems are developed which contribute to air and water monitoring, and a geographic information system is used to integrate multiple data sets in support of all EPA programs.

National Science Foundation

The National Science Foundation (NSF) is the principal supporter of academic research in atmospheric sciences and ground-based astronomy. Major events in the astronomical sciences during 1989 included the use of the Very Large Array radio telescope, in conjunction with NASA's Deep Space Network, to acquire data relayed by the Voyager 2 spacecraft during its encounter with Neptune. During 1989, astronomers mapped the galaxy distribution in the nearby universe, revealing an inhomogeneous distribution of matter, challenging current theories of cosmology. Astronomers also reported the discovery of a population of faint blue galaxies, perhaps the first in the universe to be formed. A combination of measurements by cosmologists at the South Pole and a NASA satellite allowed the cosmic microwave background radiation spectrum to be measured over a wider wavelength range than possible from elsewhere on Earth or space.

In atmospheric sciences, the MAX'91 program, designed to study solar disturbances during the current period of high solar activity, was launched. During 1989, scientists reported that studying solar-like stars can assist in predicting our own sun's activity cycles, thus increasing our ability to project future trends in global climate change. In Antarctica, measurements were taken of very-low-frequency radio waves transmitted by the Soviet satellite AKTIVNY. Also in Antarctica, NSF's ultraviolet-radiation monitoring system was upgraded to provide a data center with high standards of quality assurance.

Smithsonian Institution

The Smithsonian Institution conducts space science research at the Smithsonian Astrophysical Observatory (SAO) in Cambridge, MA, and at the Center for Earth and Planetary Studies and the Laboratory for Astrophysics at the National Air and Space Museum in Washington, D.C. The Museum's exhibits, lectures, and education programs contribute significantly to public understanding of space research. SAO also conducts programs designed to improve pre-college science instruction and serves as North American gateway for SIMBAD, the international astronomical computer database. The Roentgen satellite launched June 1, 1990, carries a High-Resolution Imager built by SAO to make detailed studies of cosmic x-ray sources. X-ray data on thousands of objects produced earlier by the Einstein (HEA0-2) satellite was converted to CDROM (compact disc-read only memory) format and made available to all qualified scholars at no cost. Additional observations obtained during the slew mode of the Einstein survey, long believed to be unusable, were retrieved by SAO scientists and converted into a new sky catalog. A rocket-borne SAO-IBM telescope made the highest resolution x-ray images ever of the sun's corona; another instrument carried by a NASA balloon over Australia observed a host of x-ray objects, including the Crab Nebula and Supernova 1987a. And, nearly two decades after Apollo astronauts returned samples of lunar soil, an SAO researcher identified a completely new rock type amidst the lunar material.

Department of State

The Department of State, through its Bureau of Oceans and International Environmental and Scientific Affairs, works with NASA on all international and foreign policy aspects of American space programs. Department of State activities during this period have included hosting a Government-level review of international space station cooperation and negotiation of arrangements for space shuttle emergency-landing facilities in countries around the globe. The State Department's Bureau of International Communications and Information Policy has taken the lead in representing U.S. interests in INTELSAT (the International Telecommunications Satellite Organizations) and INMARSAT (the International Maritime Satellite Organization), two international organizations involved in space issues.

Arms Control and Disarmament Agency

The United States Arms Control and Disarmament Agency (ACDA) has a role in space policy and research because of its arms control mandate. During FY 1990, ACDA served as a principal support agency in U.S. negotiations with the Soviet Union in the Defense and Space Talks in Geneva. Furthermore, during FY 1990, ACDA was the lead U.S. agency at multilateral discussions on space arms control at the United Nations General Assembly and at the Conference on Disarmament in Geneva. ACDA is represented at National Space Council meetings when issues related to arms control are discussed. ACDA is a member of the Arms Control Policy Coordinating Committee, whose charter includes arms control issues related to space, and the Nonproliferation Policy Coordinating Committee, whose charter includes certain space-related issues in the context of missile nonproliferation policy.

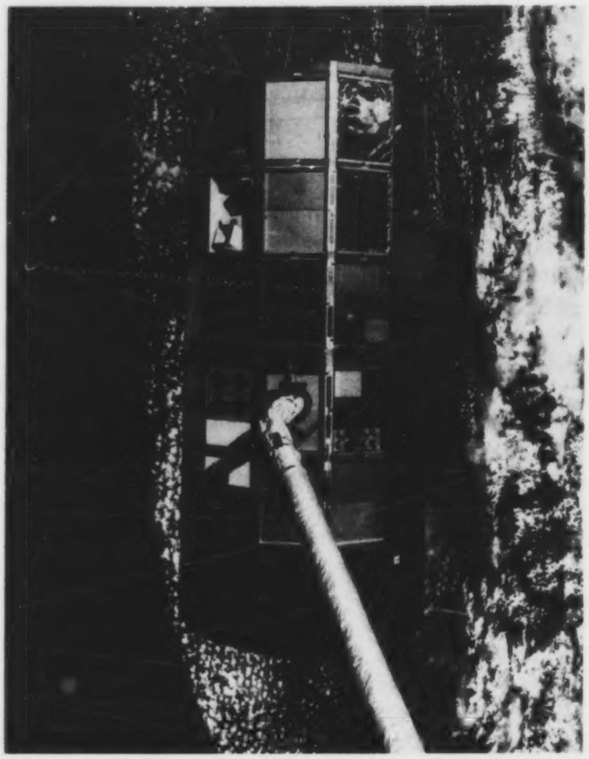
United States Information Agency

During the 20th anniversary of the Apollo lunar landing, the United States Information Agency (USIA) highlighted NASA's historic role in space exploration and increasingly important scientific missions to help protect Earth's environment. The Hubble Space Telescope and prospects for enhanced international cooperation in space exploration, as well as the President's call for the establishment of a manned scientific outpost on the moon, insured continuing overseas interest in USIA's coverage of NASA's many activities. With a wide variety of means at its disposal to publicize NASA initiatives to foreign audiences, ranging from WORLDNET (USIA's international satellite television network) TV interviews, international teleconferences and Voice of America broadcasts to Wirefile File articles, and American experts traveling overseas, USIA remains uniquely equipped to continue to tell the world about U.S. progress in space sciences and exploration.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA), established in 1958, is responsible for planning, conducting, and managing civilian research and development activities in aeronautics and space. Other Federal agencies, State, local, and foreign governments, as well as educational institutions and private industry, also share in NASA's programs.

NASA's mission continues to reflect the intent of Congress in creating the agency: that is, to explore space for peaceful purposes with international cooperation, for the benefit of all humankind. Technological advances have resulted in significant economic and social benefits for the United States and other nations and remain the catalyst for national pride, progress, and achievement. The continued success of NASA's programs will allow the United States to maintain its leadership status in aeronautics and space.



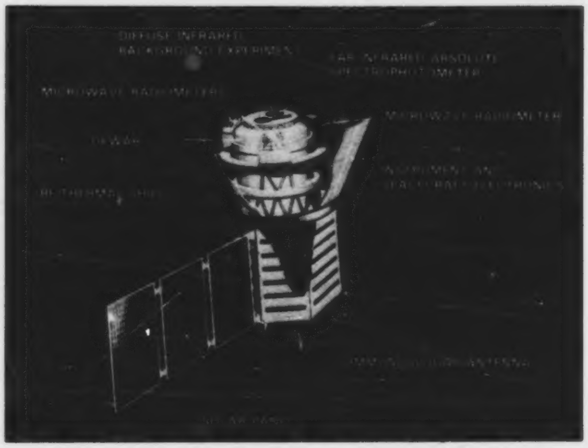
Retrieval of the Long Duration Exposure Facility by the Space Shuttle Columbia (STS-32), January 12, 1990, using the Canadian-built remote manipulator system.

Space Science and Applications

NASA's Office of Space Science and Applications plans, directs, executes, and evaluates NASA programs directed towards the space environment; conducts a scientific study of the universe to solve practical problems on Earth; and provides the scientific research foundation for expanding the human presence beyond Earth into the solar system. Research and program activities involve the characterization of Earth and its environment, the exploration of the solar system and near universe, and the observation of the distant universe. Disciplines within the Office of Space Science and Applications include astrophysics, solar system exploration, space physics, Earth science and applications, life sciences, microgravity science and applications, and communications and information systems.

Astrophysics

The NASA Astrophysics program has as its objective the study of the origin and evolution of the universe, the fundamental physical laws of nature, and the birth of stars, planets, and ultimately life. Research in these areas requires observations at wavelengths absorbed by Earth's atmosphere, and therefore must be conducted from space-borne observatories. The program is centered around a series of space observatories, supported by a


DIFFUSE INFRARED BACKGROUND EXPERIMENT
FAR INFRARED ABSOLUTE SPECTROPHOTOMETER
MICROWAVE RADIOMETER
MICROWAVE RADIOMETER
DEWAR
INSTRUMENT AND SPACECRAFT ELECTRONICS
SOLAR PANEL

Artist's rendition of the Cosmic Background Explorer, launched November 1989.

Near-infrared image showing a new view of the Milky Way obtained by the Diffuse Infrared Background Experiment on the Cosmic Background Explorer.

The Hubble Space Telescope before its release from STS-31 Discovery's remote manipulator system, with the solar panels extended but the antennae not yet deployed.

research base of instrument developments, sub-orbital research activities, data analyses, and theoretical studies.

The four Great Observatories—the Hubble Space Telescope, the Gamma-Ray Observatory, the Advanced X-ray Astrophysics Facility, and the proposed Space Infrared Telescope Facility—will provide significantly improved sensitivity and resolution over their respective regions of the electromagnetic spectrum. Smaller spacecraft in the Explorer series are used for exploration, all-sky surveys, specific studies, or unique investigations inappropriate for the Great Observatories. As part of the sub-orbital program, rockets, balloons, and aircraft provide the means to make preliminary observations, conduct selected low-cost investigations, test instrumental concepts, and to train groups capable of developing instruments for future space missions.

Cosmic Background Explorer. The Cosmic Background Explorer (COBE) was successfully launched on November 18, 1989 and carries three highly sensitive instruments which have been focused on unlocking the mysteries of the early epochs of the universe. Two of these instruments were designed to examine radiation (millimeter and submillimeter radio waves) from the Big Bang, the primordial explosion thought to have marked the creation of the universe. The third instrument maps the sky in the far-infrared wavelengths, searching for emissions that may originate from the earliest stars and galaxies. On June 16, 1990, COBE completed its first all-sky survey. COBE's supply of liquid helium, used to maintain the extremely low temperatures required for its observations, was fully depleted on September 21, 1990, as COBE entered a new phase of operations.

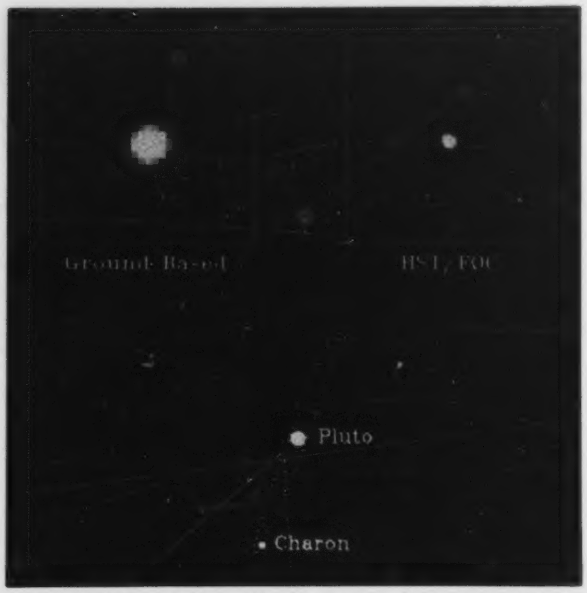
Hubble Space Telescope. During 1989, NASA completed final preparations for the launch of the Hubble Space Telescope (HST). On April 24, 1990, HST was launched aboard the orbiter Discovery as part of the STS-31 mission. Initial on-orbit observations revealed that HST's primary mirror was improperly fabricated, producing spherical aberration, and resulting in an inability to focus light in a single, precise point. Despite this error, early results from HST include impressive images that are providing important scientific information. Preparations are under way to alter the optics of the second generation instruments to fully alleviate the effects of the spherical aberration. Preparations are also continuing for the previously planned servicing mission in 1993.

Gamma-Ray Observatory. As an integral part of NASA's Great Observatories program, the Gamma-Ray Observatory (GRO) will make possible a better understanding of the structure and dynamics of our Milky Way galaxy, the formation of elements, and the origins and evolution of the universe. GRO includes four large, sophisticated instruments designed to study a broad range of gamma rays. These advanced instruments can detect gamma-ray photons, measure their energies, and determine their origin with unprecedented resolution and sensitivity. GRO will be deployed from the space shuttle as part of the STS-37 mission during 1991. Initially, GRO will conduct a more detailed survey of the gamma-ray universe than previously obtained. Later, GRO will observe in greater depth intriguing objects that were identified during the initial survey.

Advanced X-ray Astrophysics Facility. The third of the Great Observatories, the Advanced X-ray Astrophysics Facility (AXAF) will observe celestial sources in the x-ray part of the electromagnetic spectrum. Many of the most fundamental and exciting objects in the universe radiate in x rays, permitting AXAF to address some of the most fundamental questions in astronomy and astrophysics. During 1989, NASA initiated the development of the first and largest pair of AXAF's mirrors, which are scheduled for completion in 1991. During 1990, the development of AXAF's science instruments was initiated and significant progress was made on the mirror development effort. AXAF is being designed for a 1997 launch aboard the space shuttle.

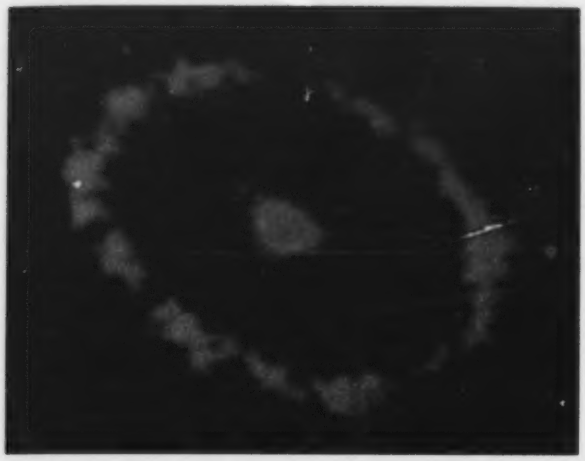
Space Infrared Telescope Facility. The fourth Great Observatory, the proposed Space Infrared Telescope Facility (SIRTF) will observe in the critical infrared wavelengths, completing coverage by the Great Observatories of each of the four major regions of the electromagnetic spectrum. SIRTF, a 1-meter-class, cryogenically-cooled observatory, will be used to study the birth and death processes of stars and distant galaxies, and the origins and evolution of comets, asteroids, and the cold planets of our solar system. Studies completed during 1989-90 concluded that SIRTF should be placed in high-Earth orbit at an altitude of approximately 100,000 kilometers. In addition, these studies provided significant insight into the primary and secondary mirror mechanisms, as well as the detector materials that will used in SIRTF's scientific instruments.

Roentgen Satellite. A cooperative flight project with the Federal Republic of Germany and the United Kingdom, the Roentgen satellite (ROSAT) will provide an all-sky, x-ray survey of unprecedented sensitivity. During 1989, the Germans completed all remaining structural and environmental testing, and completed integration of the scientific instruments into the spacecraft. ROSAT was delivered in late 1989 to the Cape Canaveral Air Force Station, where it was launched on June 1, 1990, aboard a Delta-II expendable launch vehicle supplied by the United States. ROSAT has completed its planned on-orbit check-out period and has initiated its all-sky survey, which is planned for completion in early 1991. The pointed phase of ROSAT's operations will commence upon completion of the all-sky survey. During this phase, which includes U.S. Guest Observer participation, ROSAT will point at selected regions of the sky for more detailed studies of various x-ray sources.



On the right is the clearest picture ever of the planet Pluto, and its huge companion "moon" Charon, using ESA's Faint Object Camera on the Hubble Space Telescope, October 1990. On the left, for comparison, is the best ground-based image ever taken using the Canada-France-Hawaii telescope in Hawaii.

Stratospheric Observatory for Infrared Astronomy. The proposed Stratospheric Observatory for Infrared Astronomy (SOFIA) is a joint project being studied by NASA with the Federal Republic of Germany.



Mysterious gaseous ring seen with unprecedented detail around Supernova 1987a, with the tightly knotted debris from the stellar explosion at the center of the ring, taken with ESA's Faint Object Camera on the Hubble Space Telescope, August 23, 1990.

Image of Saturn taken with the Hubble Wide Field/Planetary Camera, showing greater detail in the planet's ring system and cloud belts than can be achieved with ground-based telescopes, August 26, 1990.

This project consists of a 2.5-meter-diameter infrared telescope mounted in an airborne observatory. An open port in the upper side of a modified Boeing 747 aircraft provides viewing. With a planned 20-year lifetime, SOFIA will provide a foundation for research, instrument development, and the training of young scientists. Its excellent spatial and spectral resolution will assure complimentary support of the Great Observatories. NASA will supply a major part of the telescope system and participate in the flight program. During 1989, concept definition studies on the aircraft and the telescope were completed. Technology demonstration studies were initiated on critical telescope issues, as well as wind tunnel tests to verify the aircraft opening design concept. During 1990, a Non-Advocate Review (NAR) of the SOFIA program was completed with the NAR team endorsing, without major revision, SOFIA's continued development.

Explorer Platform Missions. During 1989, the development of the scientific instruments for the Extreme Ultraviolet Explorer (EUVE), the first payload to use the reusable explorer platform spacecraft, was completed and calibration was begun. The instruments were delivered to the Goddard Space Flight Center in early 1990 for integration into the payload module. The explorer platform is currently under development and will be delivered to Goddard in late 1990 for integration with the EUVE payload module. EUVE is scheduled for launch in 1991, aboard a Delta II expendable launch vehicle. The X-ray Timing Explorer (XTE), the second payload scheduled for use on the explorer platform, completed its definition phase and initiated its development phase during 1989. The XTE payload will replace the EUVE payload during an on-orbit changeout performed by a space shuttle crew, scheduled for early 1995.

Small Explorer Program. During April 1989, three missions were selected for development under the Small Explorer program: the Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX); the Fast Auroral Snapshot Explorer (FAST); and the Submillimeter Wave Astronomy Satellite (SWAS). SAMPEX is scheduled for launch on a Scout expendable launch vehicle in mid-1992 and will determine the origin of various contributions to the energetic, charged particles arriving at Earth from the sun and interstellar space. FAST will examine physical processes high above Earth that result in aurora, while SWAS will determine the presence of water and other important molecules in interstellar space. By the end of 1989, the development of SAMPEX was well under way. During 1990, NASA completed concept studies and initiated a review of the proposed launch dates for FAST and SWAS (originally 1993 and 1994, respectively).

Astro-D. The Astro-D mission is a cooperative flight project with Japan, which is scheduled for launch in February 1993, from the Kagoshima Space Center in Japan. Astro-D will conduct x-ray astronomy and spectroscopy; NASA's contribution will include lightweight x-ray mirror assemblies and spectroscopic x-ray detectors, which will be delivered to Japan in 1991. During 1989-90, work continued on the design and development of the scientific instruments and the fabrication of breadboards.

X-ray Multi-Mirror Mission. During 1989-90, the European Space Agency (ESA) continued moving forward with this approved "cornerstone" mission. The X-ray Multi-Mirror Mission (XMM) is devoted to high throughput x-ray spectroscopy of celestial objects such as stellar coronae, binary star systems, supernova remnants, and active galactic nuclei. XMM will be launched into an eccentric high-Earth orbit in 1998. NASA has agreed that U.S. science teams will provide key components of two scientific instruments on XMM and two mission scientists, which will secure optimal scientific return from the mission.

High Energy Astronomy Observatories. Analysis of data from the three missions in the High Energy Astronomy Observatories (HEAOs) series of x-ray and gamma-ray astronomy project continued in 1989-90, with emphasis on archiving the most essential data products. A source catalog of several thousand valuable sources detected by HEAO-2 (Einstein) has been produced on compact disk and distributed to the scientific user community. Data from the HEAO missions are now part of the Astrophysics Data Program archives and remained in active use by the astrophysics community during 1989-90.

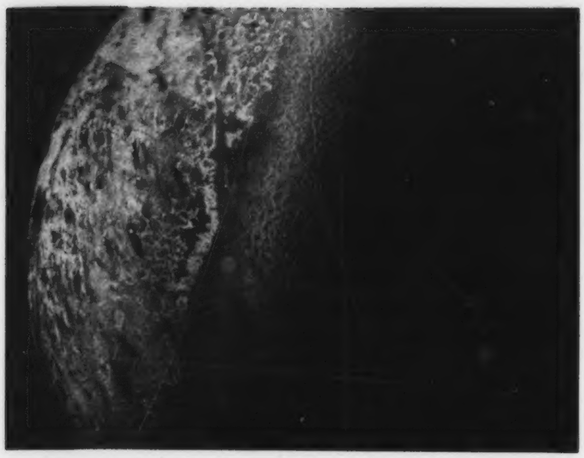
International Ultraviolet Explorer. During 1990, the International Ultraviolet Explorer (IUE) entered its 13th operational year and continued to contribute thousands of astronomical spectra observations of such objects as comets, planets, all manner of stars, and even distant extragalactic objects such as quasars. In August 1989, IUE provided contemporaneous ultraviolet spectra of Neptune and Triton at the time of the Voyager flyby. Also, development of a single-gyro control system for IUE (initially designed for three gyros) brightens the prospects for continued operations of this geosynchronous satellite observatory.

Infrared Astronomical Satellite. Scientific interest remains high in the Infrared Astronomical Satellite (IRAS) data nearly 7 years after the end of satellite operations. Significant discoveries continue using IRAS data, including evidence that distant galaxies go through explosive episodes of stellar formation much more often than galaxies in the immediate proximity to Earth and that all sun-like stars are surrounded by material that may condense into planetary systems. IRAS data have been collected in a new catalog of infrared sources containing over 100,000 previously unknown galaxies and another 100,000 previously unknown stars.

Solar System Exploration

NASA's Solar System Exploration program includes scientific exploration of the various bodies in the solar system—other planets, their moons, comets, and asteroids—and of the interplanetary medium around them. The objectives of solar system exploration are the following: 1) to determine the nature of planets, moons, and small bodies (comets and asteroids) in order to understand the origin, present condition, and evolution of the solar system; 2) to understand Earth better through comparative studies of other planets and the processes that shape them; 3) to understand how the physical and chemical characteristics of the solar system contributed to the origin and development of life; and 4) to provide scientific assessments of potential resources available in near-Earth space.

Achieving these goals involves a balanced and progressive program to study all solar system objects: the terrestrial (Earth-like) inner planets, the giant (Jupiter-like) outer planets, and the small bodies (comets and asteroids). Spacecraft missions to these objects are carried out in an evolutionary series, beginning with relatively simple flyby reconnaissance missions. These missions are followed by more complex ones (orbiters, landed stations, and sample returns) that provide increasingly detailed and specialized information. The spacecraft



Photomosaic taken by Voyager 2 of Neptune's largest satellite, Triton, assembled from 14 individual frames, showing the great variety of its surface features, including the "cantaloupe" terrain in the upper left. Note the dark volcanic plumes visible in the lower center.

missions are supported by an essential foundation of diverse ground-based activities—mission operations and data analysis, scientific research and analysis, and advanced programs studies.

Pioneer Missions. Pioneers 10 and 11 (as well as Pioneers 6, 7, and 8) continue to collect valuable data about the fields, particles, and plasma waves of the outer solar system. In flight for nearly two decades, and operating beyond their qualification limits, Pioneers 10 and 11 remain in working order, with most of their scientific instruments functioning well. In 1990, Pioneer 10, the furthest manmade object from Earth, had traveled more than 50 astronomical units (the distance of Earth from the sun) away from Earth, toward the heliosphere. Having passed beyond the farthest planets, the Pioneers will continue to explore the far edges of the solar heliosphere as they leave the sun in opposite directions. They will investigate the boundary of the sun's magnetic and plasma environment, the interaction of the solar fields with interstellar space, and, if possible, measure the properties of interstellar space itself beyond the sun's influence. Both spacecraft are powered by radioactive thermal generators (RTGs) whose power has been reduced by about one half since launch. Pioneer 10 is expected to have enough power to continue operating until late 1996, while Pioneer 11 will run out of power in late 1992.

Pioneer Venus Orbiter. The Pioneer Venus Orbiter (PVO) continues to collect important scientific data from its orbit around Venus after more than a decade of operations. Electrical power available from the solar cells has slowly declined because of damage by the intense solar radiation, but the spacecraft battery continues to operate and the instruments continue to function. The PVO studies the chemical and physical processes of Venus' upper atmosphere, particularly through its interaction with the solar wind. Before PVO enters the Venusian atmosphere and burns up in 1992, the remaining spacecraft fuel will be used to control the orbit's orientation and altitude to maximize the data obtained about the planet's atmosphere.

Voyager. In August 1989, the Voyager 2 spacecraft made its fourth planetary flyby, this time past the mysterious blue planet Neptune, more than 4.43 billion kilometers (2.75 billion miles) from Earth. In this encounter, the first time Neptune has ever been observed close up, Voyager 2 provided exciting new information about Neptune's atmosphere, magnetic field, rings, and moons, sending the data to Earth in radio signals that, even at the speed of light, took over 4 hours to arrive. The Voyager 2 spacecraft performed flawlessly despite its tremendous distance from Earth, which forced substantial new modifications in both the operation of the spacecraft and its instruments and in the reception and processing systems on Earth. The images returned of Neptune and its largest satellite, Triton, were of remarkable quality and the initial scientific reports, published in *Science*, indicated that the scientific data collected will prove to be significant. Voyagers 1 and 2 are now leaving the solar system, in approximately the same direction as Pioneer 11. As the Pioneers cease to operate, the Voyagers will continue to explore the outer heliosphere.

New Age for Solar System Exploration. During 1989 and 1990, several near-term solar system exploration goals were spectacularly achieved. In 1989, the Magellan and Galileo missions were successfully launched by the space shuttle toward Venus and Jupiter, respectively, the first planetary missions to be launched in more than a

VENUS
EARTH
SATURN

As Voyager 1 left the solar system it captured, on February 14, 1990, this first ever "portrait" of our solar system as seen from the outside. These blown-up images are of six of the planets: Venus, Earth, Jupiter, Saturn, Uranus, and Neptune.

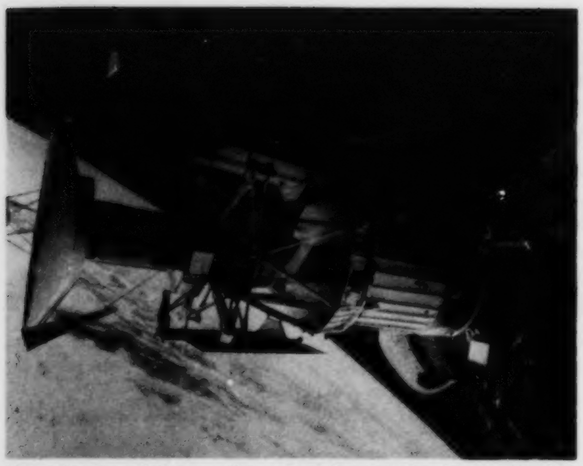
This drawing shows the 60 frames taken by Voyager 1 to obtain the portrait of six of the planets.

decade. And a major step in exploration of the outer solar system was taken with the 1990 launch of the Ulysses spacecraft, also to Jupiter, and the approval of the dual CRAF-Cassini mission, which will be launched in the mid-1990s to explore an asteroid, a comet, Saturn, and its large moon, Titan.

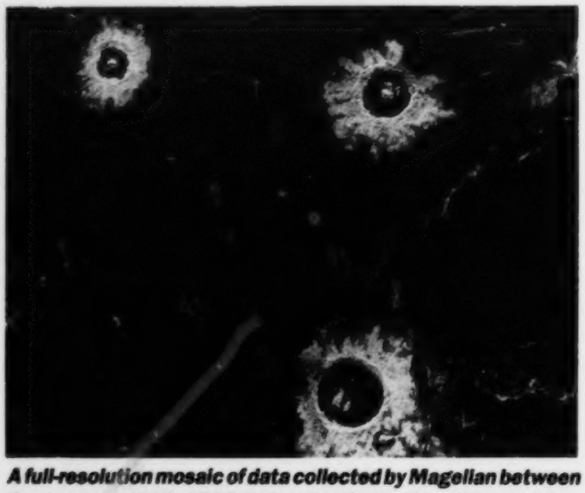
Magellan. On May 4, 1989, the Magellan mission was launched toward Venus by the space shuttle to completely map the planet's surface landforms. It was the first planetary mission launched by the space shuttle, and the first shuttle-launched spacecraft to leave near-Earth orbit for interplanetary space. Magellan arrived at Venus on August 10, 1990. The spacecraft began radar mapping operations in late FY 1990, after early radar test images were released in August. Magellan is exploring the surface topography and interior structure of Venus through the use of high resolution radar mapping, altimetry, microwave radiometry, and through the precise measurement of Venus' gravitational field. The Magellan mission will add to our knowledge of Venus gained from previous missions like the Pioneer Venus Orbiter, Arecibo, and the Soviet Venera investigations. Magellan's scientists include participants from each of these earlier investigations.

Galileo. On October 18, 1989, the Galileo spacecraft was launched toward Jupiter. The second planetary mission to be launched by the space shuttle, Galileo is heading back toward Earth from Venus, having made the first of three planetary gravity-assist swingbys (one at Venus and two at Earth) needed to carry it out to Jupiter in December 1995. There, the Galileo mission will be the first to make direct measurements from an instrumented probe within Jupiter's atmosphere and the first to conduct long-term observations of the planet, its magnetosphere, and satellites from orbit. Galileo's probe will be the first atmospheric probe for any of the outer planets. Along the way, Galileo will use its flybys to explore several other worlds: Venus, Earth, the moon, and two asteroids.

Ulysses. The Ulysses mission, launched aboard the shuttle and an inertial upper stage on October 6, 1990, is an international cooperative mission developed by NASA and the European Space Agency (ESA). The mission will explore the sun and the heliosphere at previously unexplored high solar latitudes, collecting scientific data in the solar pole regions. To view the solar poles, the spacecraft must leave the ecliptic plane, the plane in which Earth orbits the sun. The spacecraft will make detailed measurements of the sun's corona, the origin and acceleration of the solar wind into space, and the composition and acceleration of energetic atoms from the sun in solar flares and violent solar events. Ulysses is traveling towards Jupiter, where it will be projected out of the ecliptic plane



Magellan as it leaves the cargo bay of the Space Shuttle Atlantis (STS-30), in orbit over the city of New Orleans.



A full-resolution mosaic of data collected by Magellan between September 15-18, 1990 during the first orbits of Venus. View shows three large impact craters.

toward the sun's southern pole. It will begin investigation of the higher latitudes of the sun's south pole in May 1994 and conclude its investigation in September 1995 at the sun's north pole.

Mars Observer. The Mars Observer mission will expand the pioneering discoveries of Mariner 9 and Viking by making a 2-year global scientific survey of the red planet, including the mineral and chemical composition of its surface, the composition and dynamics of its atmosphere and volatiles, and the nature of its magnetic and gravitational fields. The Mars Observer mission is planned for launch in 1992 on a Titan-3/transfer orbit stage expendable launch vehicle combination. Arriving at Mars in 1993, the spacecraft will be inserted into a polar orbit. Mapping will start in December 1993 and will continue for a full Martian year (about 2 Earth years). Critical design reviews for the spacecraft and many of the instruments were completed in 1989, with hardware development continuing in 1990.

CRAF-Cassini. The CRAF-Cassini program was approved in 1989 as a new start for FY 1990. Building on Pioneer and Voyager discoveries, these two missions will provide unprecedented information on the origin and evolution of our solar system and will help us understand how the chemical building blocks necessary for the evolution of life were formed. A joint program with the European Space Agency, the CRAF-Cassini program, the missions will utilize a common Mariner Mark II spacecraft and common elements of design, fabrication, test, and integration. CRAF (the Comet Rendezvous/Asteroid Flyby) will be launched in 1995 to fly closely by the asteroid Hamburga in 1998 and then to rendezvous with comet Kopff in the year 2000 for a 3-year period of intensive study. During this period, CRAF will implant a penetrator in the comet's nucleus to analyze for the first time the solid material of which a comet is made. Cassini will be launched in 1996. It will fly past the asteroid Maja in 1997, execute a gravity-assist flyby past Jupiter in 2000, and arrive at Saturn in 2002 for a 4-year study of the Saturnian system. After entering orbit around Saturn, Cassini will deploy a probe to pass through the thick, orange atmosphere of Saturn's largest moon Titan and measure its atmospheric composition. The orbiting spacecraft will observe Saturn and its moons, using its radar to map Titan's hidden surface.

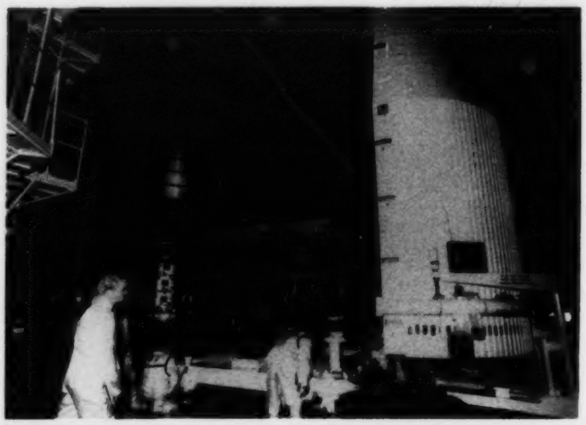
Research and Analysis. In 1989 and 1990, the Research and Analysis program supported active research in several important disciplines—planetary astronomy, planetary atmospheres, planetary materials and geochemistry, and planetary geology and geophysics. These activities, most of which focus on university-based research groups and on training new scientists, support the Solar System Exploration program by developing the research base and instrumentation needed for future missions, by providing effective analysis and long-term use of mission data, and by generating exciting research results that cannot be obtained from flight missions.

Mission Operation and Data Analysis. Mission Operation and Data Analysis (MO&DA) supported the operations of currently active missions—Pioneers 6-8, 10, and 11; Pioneer Venus; and Voyager 1 and 2—and analyzed their data. The MO&DA program also continued its activities in support of launch operations for Ulysses and the upcoming Mars Observer launch.

Advanced Programs. Advanced programs support essential studies for planning future planetary missions. In 1989, significant progress was made on advanced studies, including work on the Lunar Observer mission, which will make a global scientific exploration of the moon. Advanced studies also continued for Mars missions, particularly a Mars Rover sample return. In addition to the moon and Mars studies, two important payloads are under study for possible inclusion in the initial phase of Space Station Freedom in the mid- to late 1990s: the Cosmic Dust Collection Facility, which will capture small dust particles that may have come from comets or from interstellar space, and the Astrometric Telescope Facility, which will initiate a long-term search for planets around other stars.

Space Physics

The NASA Space Physics program focuses on: 1) the sun, both as a star and as the dominant source of energy, plasma, and energetic particles in the solar system; 2) the interactions between the solar wind and solar-system bodies including Earth and other planets; 3) the nature of the heliosphere both in its steady state and in its dynamic configuration; and 4) the origin, acceleration, and transport of solar and galactic cosmic rays. In 1989, a new period of maximum solar activity occurred, with its attendant increase in radiation associated with solar flares. As planning for the manned exploration of the moon and Mars proceeds, under the aegis of the Space Exploration Initiative, it becomes even more important to possess an accurate understanding of these phenomena.



Workers at the Kennedy Space Center prepare the joint NASA/DOD Combined Release and Radiation Effects Satellite for encapsulation in the nose fairing of an Atlas Centaur rocket.

Combined Release and Radiation Effects Satellite Program. The NASA objectives of the Combined Release and Radiation Effects Satellite (CRRES) program are to study the ionospheric and magnetospheric plasma, and Earth's magnetic field through chemical releases. Three elements of the CRRES program were accomplished in 1990. In April, the Pegsat spacecraft was launched on the first Pegasus vehicle and conducted two chemical releases over northern Canada. In July 1990, the CRRES spacecraft, a joint NASA/DOD mission, was launched. In September 1990, the first 4 of 20 chemical releases planned for the CRRES spacecraft were successfully completed.

International Solar-Terrestrial Physics Program. In 1989 and 1990, NASA continued to participate in the development of a coordinated program to measure the sun-Earth space environment in the 1990s. The International Solar-Terrestrial Physics (ISTP) program comprises two major subprograms: the Global Geospace Science (GGS) program and the Solar-Terrestrial Science Programme. NASA participates jointly in this effort with the European Space Agency (ESA) and the Japanese Institute of Space and Astronautical Sciences (ISAS). The GGS program explores global mass, energy, and momentum transfer mechanisms in and between key regions of Earth's magnetosphere. Several missions are slated to accomplish this: Wind (NASA), scheduled for launch in December 1992; Polar (NASA), scheduled for launch in July 1993; and the joint Japanese/NASA Geotail mission scheduled for launch in June 1992. Wind will provide data on the solar wind. Polar will provide data on energy input to the polar ionosphere. The two missions will operate in tandem and in conjunction with Geotail and CRRES, which will investigate the energy-storage region both in the deep magnetotail and in the Van Allen radiation belts. The ESA/NASA Solar-Terrestrial Science Programme comprises two missions: the four-spacecraft Cluster mission and the Solar and Heliospheric Observatory (SOHO). Cluster will conduct a three-dimensional microphysics investigation of the polar magnetosphere and the SOHO will investigate the sun's interior structure, the solar corona, and the solar wind. In 1989, NASA's Global Geospace Science missions, Wind and Polar, completed preliminary design review of the spacecraft systems. Work on the critical design review occurred in 1990. Also in 1989, the Memorandum of Understanding between the ISAS and NASA concerning Geotail was signed. Geotail, under development by the Nippon Electronics Corporation, moved toward a flight system critical design review in 1990.

Orbiting Solar Laboratory. Studies continued on the proposed Orbiting Solar Laboratory (OSL). The OSL is a free-flying satellite in a sun-synchronous polar orbit. Under consideration as a candidate new start mission, the mission will produce continuous solar observational data of unprecedented detail in white-light, ultraviolet, and extreme-ultraviolet images and spectra simultaneously. The net result will be virtual movies of solar processes as they emerge from the sun's interior and are transformed and/or evolve through the upper layers of the sun's atmosphere. Knowledge derived from the OSL will contribute seminally to our understanding of the spectacular eruptions of solar flares, which may improve our solar cycle prediction abilities, and prove valuable during times of high activity when astronauts risk prolonged exposure to harmful radiation. In 1989 and 1990, the phase B science and instrumentation work on the OSL proceeded.

Solar-A Program. NASA is providing one of the four instruments for the Japanese Solar-A mission, which will generate images of soft and hard solar x rays during the current period of maximum solar activity. The joint mission progressed satisfactorily in 1989 toward its scheduled launch in 1991.

Tethered Satellite System. The Tethered Satellite System (TSS), sponsored jointly with Italy, will examine the electrodynamic effects of large, conducting space systems as they interact with ambient plasma and Earth's magnetic field. The spacecraft is to be tethered at a distance of 20 km (approximately 12 miles) from the space shuttle. In 1989, fabrication of the spacecraft and the machinery that will be used to deploy it was completed. The NASA flight instrument, Research on Orbital Plasma Electrodynamics (ROPE), was also completed and delivered. In 1990, fabrication and development work continued on four other U.S. and five Italian flight instruments. Three Italian payload specialists were also selected and began training for a flight scheduled in 1991.

Solar Maximum Mission. On December 2, 1989, the Solar Maximum Mission (SMM) spacecraft re-entered Earth's atmosphere over the Indian Ocean and disintegrated, ending nearly 10 years of productive observation. SMM was launched on February 14, 1980 at the height of the last solar cycle. With the successful 1984 SMM on-orbit repair mission by the space shuttle crew, the mission's scientifically productive life was extended to study the current maximum of the solar cycle that began in 1986. SMM observations provided a better understanding of the pre-impulsive phase that precedes the first large energy release in a solar flare. SMM also provided the first measurement of sunspots in three dimensions, as well as discoveries unrelated to solar-maximum activity, for example, detection of emissions from Supernova 1987a, 10 collisions of comets with the sun, and small increases in high-altitude ozone levels in Earth's atmosphere that may be associated with global warming.

Explorer Program. The International Cometary Explorer (ICE) continued to operate in 1989 and 1990 in a heliocentric orbit at Earth's distance from the sun, but far from Earth itself. ICE data sets from comet Giacobini-Zinner and Earth's geotail region continued to be studied. Interplanetary Monitoring Platform-8 investigations included studies of solar modulation of cosmic rays, solar-wind/magnetosphere coupling, solar-wind dynamics, and magnetospheric dynamics. IMP-8 remains critical to the support of deep-space missions such as Ulysses, Pioneer, and Voyager and has become the primary monitor of solar activity as it builds to a new maximum. Dynamics Explorer continued to provide data for investigations of the coupling of energy, electric currents, electric fields, mass, and waves between the magnetosphere, the ionosphere, and the atmosphere.

Active Magnetospheric Particle Tracer Explorer/Charge Composition Explorer. The Active Magnetospheric Particle Tracer Explorer/Charge Composition Explorer (AMPTE/CCE) spacecraft ceased useful operations in 1989 after more than 4 productive years. During the mission's lifetime, AMPTE/CCE investigators conducted numerous studies of the contributions of ionospheric matter and solar wind to Earth's radiation zones, of the interaction between an artificially injected cold plasma and the natural, flowing space plasmas; and of the chemical composition, electrical charge state, temperature, and temporal changes of natural-particle populations in the Van Allen radiation belt region of the magnetosphere.

Suborbital Program. Scientific experiments in space can often be performed inexpensively through the use of sounding rockets or balloons, allowing project teams to design, build, and fly experiments within a period of 1 to 2 years. The quick turnaround time not only allows for major scientific results, but also serves very effectively as a means of training graduate students and young scientists for advanced experimental research. NASA can support 30-40 sounding rocket launches annually. In September 1989, a NASA Black Brant X sounding rocket carried a new x-ray imaging instrument created by the Smithsonian Astrophysical Observatory and IBM. Using a multilayer mirror-coating technique developed by IBM, the instrument was able to form precisely focused optical images of the sun as revealed in soft x-ray emissions at the exact moment of a solar flare. The result was the most abundantly detailed series of solar flare images in soft x-rays ever obtained. The technology used may have applications in projects planned for the 1990s as it registers a significant step toward our development of the ability to anticipate and respond to solar flares.

NASA continues to maintain the capacity to launch 40-50 scientific balloons annually. A successful test in November 1989 involved a 40-million-cubic-foot balloon that proved capable of carrying a 5,600-pound suspended weight to an altitude of about 123,000 feet. The Australian campaign continued the investigation of Supernova 1987a. Preparations were completed in 1989 for a series of test flights in a newly established NASA/NSF program to develop the capability for long-duration balloon flights in Antarctica.

Advanced Studies. During 1989 and 1990, advanced studies continued on both major and moderate missions. Emphasis continued to be given to the Solar Probe, which is designed to measure small-scale solar plasma phenomena, especially particles and fields, directly from within three solar radii of the sun's surface. Results of this project promise to be revolutionary, since the portion of the solar atmosphere to be studied (the inner corona) is presently accessible only to remote sensing devices. Launch may be possible by 1999. In June 1989, three investigations were selected for the Astromag facility being planned jointly by the United States and Italy for Space Station Freedom. This facility will use a superconducting magnet attached to the space station to analyze very-high-energy cosmic rays in order to investigate the origin and evolution of matter in the galaxy and search for antimatter. Seven proposals to use the Earth Observing System polar platform were also selected. Studies continued on systems such as the Neutral Environment with Plasma Interactions Monitoring System, which would allow monitoring of many plasma, gas, and optical processes that affect Space Station Freedom payloads and operations. Further definition continued on a multiwavelength, x-ray/ultraviolet, high-resolution payload for solar physics.

Earth Sciences

The NASA Earth Science and Applications program is responsible for broad, space-based scientific studies of Earth as an integrated whole, and the processes comprising Earth system science. The U.S. Global Change Research program, coordinated by the Committee on Earth and Environmental Sciences under the Office of Science and Technology Policy, is a guiding force in setting priorities for the NASA Earth Science and Applications program.

Upper Atmosphere Research Satellite. The Upper Atmosphere Research Satellite (UARS) is the spearhead of a long-term, international program of space research concerning global atmospheric change. The UARS program will conduct the first systematic, detailed satellite study of Earth's stratosphere, mesosphere, and lower thermosphere and establish the comprehensive database needed to understand stratospheric ozone depletion and to assess the role of human activities in atmospheric change. Scheduled for launch in 1991, the UARS mission will also lay the foundation for a broader study of upper atmosphere influence on climate and climate variations. The UARS observatory instrument module structure completed qualification testing in 1989, with all 10 of the instruments delivered by January 1990. Full integration and testing of the spacecraft and instruments was completed in summer of 1990.

TOPEX/POSEIDON. TOPEX/POSEIDON is a joint U.S. (NASA) and French (CNES) mission designed to make substantial contributions to the understanding of global ocean dynamics. Radar altimeters on a well-tracked satellite will make accurate observations of the oceanic sea-surface topography. These data will enable the study and modeling of oceanic circulation and heat transport and its interaction with the atmosphere. The TOPEX/Poseidon mission is a precursor to the altimetry instruments included in EOS. TOPEX/POSEIDON is scheduled for a mid-1992 launch aboard an Ariane IV rocket. During 1989, significant progress was made in the satellite's design with the critical design review being successfully conducted in May 1989. Hardware fabrication for both the satellite system and instruments began in 1989 and continued through 1990, with integration of the satellite beginning in the spring of 1991.

NASA Scatterometer. When the U.S. Navy Remote Ocean Sensing System satellite was canceled in 1988, NASA submitted a proposal to NASDA, the Japanese space agency, to include the NASA Scatterometer (NSCAT) as part of the Japanese Advanced Earth Observing Satellite (ADEOS) payload. During 1990, NSCAT was confirmed for flight on ADEOS and is developing into an international cooperative effort. NSCAT will contribute systematic high-resolution wind observations over the ocean, serving as a precursor to the scatterometry elements of the Earth Observing System program. These data are critical to understanding processes in which the oceans and atmosphere play a role in moderating Earth's climate. NSCAT will be a key contributor to international ocean research. NSCAT is planned to be incorporated into the new Earth Probes program, proposed for a new start in FY 1991.

Earth Observing System. The Earth Observing System (EOS) is a comprehensive program of Earth system science, which will obtain and analyze long-term comprehensive observations from space. EOS is a critical element of NASA's Mission to Planet Earth program and the major NASA contribution to the interagency U.S. Global Change Research Program (USGCRP). EOS science will benefit from an extensive data and information system, supported by a series of polar-orbiting platforms carrying a suite of internationally provided instrumentation. The Earth Observing System is proposed as a new start for FY 1991. In 1989, a non-advocacy budget review was conducted in preparation for the submission of the FY 1991 EOS initiative. During 1990, the National Academy of Sciences conducted and released their review of the USGCRP and the important contribution of EOS to that program.

The interdisciplinary research investigations selected in 1988 continued to provide the scientific foundation for EOS. Definition and preliminary design phase studies for the EOS instruments continued in 1989 and 1990, leading to final confirmation of the payload for the first platform expected in October 1990. Planning for the EOS Data and Information System (EOSDIS) also made significant progress in 1989 and 1990, with planned release of the Request for Information for EOSDIS scheduled for October 1990.

International cooperation continued through the Earth Observations International Coordination Working Group (EO-ICWG), which met twice in 1989 in Ottawa, Canada (April), and Washington, DC (November), and once in 1990 in Paris (June). EO-ICWG is coordinating the payload planning for the NASA, European Space Agency (ESA), and Japanese polar platforms, as well as addressing common instrument interfaces and developing agreements on various aspects of the polar Earth observation program which could be formalized in the future.

Sea-Viewing Wide Field Sensor. The Sea-Viewing Wide Field Sensor (SeaWiFS) is a global ocean color mission designed to deliver worldwide observations of ocean radiance for research in biogeochemical processes, climate change, and oceanography. SeaWiFS is planned for launch as a precursor to the EOS and is a follow-on ocean color sensor to the Coastal Zone Color Scanner, the first and only ocean color satellite instrument to date, which flew on Nimbus 7. During 1989 and 1990, NASA worked to define the mission requirements to develop the SeaWiFS as a commercial satellite mission. In this scenario, NASA would procure the data stream from a commercial entity which would build, own, and operate the instrument and retain rights to sell the data stream to other potential clients.

Operational Meteorological Satellites. NASA continues to support the National Oceanic and Atmospheric Administration's (NOAA) operational polar and geostationary weather satellite program by acting as NOAA's agent to procure the needed satellites and instruments and to arrange for launch and on-orbit checkouts prior to transferring control of them over to NOAA for routine operations. The polar-orbiting NOAA-10 (launched in September 1986) has far exceeded its 2-year design life; its intended replacement, NOAA-D, is currently in storage to be launched no earlier than the spring of 1991. Integration and test of NOAA-I, the intended replacement for NOAA-11, is proceeding smoothly and the spacecraft is scheduled to be delivered by late 1991. Since the failure of the geostationary GOES-6 in January 1989 (9 months beyond its 5-year design life), U.S. coverage has been provided by a single satellite, GOES-7, which is moved seasonally to provide optimal hurricane and winter storm coverage. GOES-I, scheduled for launch no earlier than early 1992, will replace GOES-6. A preliminary definition study of the next generation of geostationary weather satellites began in June 1989 and was completed in 1990.

Airborne Arctic Stratospheric Expedition. NASA and NOAA jointly coordinated the 6-week Airborne Arctic Stratospheric Expedition to study stratospheric chemistry and meteorology over the Arctic. This expedition was a follow-on to a similar aircraft study in 1987 of ozone loss over Antarctica. The Arctic expedition took place during early winter when polar stratospheric clouds are most likely to form. During early 1989, NASA ER-2 and DC-8 aircraft carrying many instruments of the same type used in the Antarctic, flew 28 missions over the Arctic as far as the North Pole to investigate the chemical and dynamical processes controlling ozone in the Arctic polar stratosphere. Preliminary results from this study indicate that the chemical composition of the Arctic polar stratosphere is highly perturbed and that these perturbations occur over a wide range of altitudes in the stratosphere. While no large ozone losses have been observed in the Arctic, strong perturbations in active chlorine were observed.

Ozone Measurements. The Total Ozone Mapping Spectrometer (TOMS) instrument provides high-resolution global mapping of total ozone on a daily basis. NASA reached final agreement with the Soviet Union in the summer of 1990 to fly a TOMS instrument on the Soviet Meteor-3 spacecraft in the fall of 1991; initial delivery of a TOMS flight unit delivery to the Soviet Union was expected in October 1990. In addition, TOMS missions in 1993, aboard a U.S. Scout spacecraft, and 1995, aboard the Japanese ADEOS spacecraft, are being prepared for submission as part of the Earth Probes initiative in the FY 1991 budget. A Solar Backscatter Ultraviolet (SBUV) instrument flew on the shuttle in October 1989 to gather on-orbit data needed to calibrate direct ozone measurements by TOMS and other NASA and NOAA satellite instruments. Preliminary analysis of the 1989 flight was conducted in the summer of 1990, with a second SSBUV mission planned for October 1990.

International Climate Assessments. Article 6 of the Montreal Protocol on Substances that Deplete the Ozone Layer requires that its international ozone control measures be reviewed in 1990 and every 4 years thereafter on the basis of currently available scientific, environmental, technical, and economic information. NASA scientists participated on panels of experts organized by the United Nations Environmental Programme (UNEP) to review relevant information. Preliminary conclusions include the prediction that total chlorine and bromine loadings of the atmosphere will approximately triple by the year 2050 and lead to continued ozone depletion. Antarctic and Arctic ozone loss would likely worsen, and the Antarctic ozone hole would not disappear until levels of atmospheric chlorine were reduced to the levels of the early 1970s.

NASA researchers also participated in the working group that prepared the Scientific Assessment of Climate Change for the Intergovernmental Panel on Climate Change (IPCC).

Climate Research. Earth Radiation Budget Experiment (ERBE) research and operations continued in 1989 and 1990 with published research discussing the cooling effect of global cloudiness and the nature of energy transfer. In addition, two scientists at Marshall Space Flight Center released the results of satellite measurements of global atmospheric temperature over the last 10 years. Their research validated the use of satellite observations by showing the close correlation between such measurements and ground and balloon measurements of the same areas. The International Satellite Cloud Climatology Project (ISCCP) is part of the World Climate Research Program which aims to produce a global, calibrated radiance data set, together with other basic information on the radiative properties of the atmosphere and surface from which cloud properties can be derived. A validated global cloud climatology will serve as an important component for a comprehensive understanding of global change. ISCCP data collection and processing is planned to continue through 1995.

First International Satellite Land Surface Climatology Project Field Experiment (FIFE-89). This activity was an extension of the successful 1987 activity in Kansas known as FIFE. Over 150 investigators in 30 teams reoccupied the Konza Prairie near Manhattan, KS for 21 days in August. Supported by six aircraft bearing state-of-the-art remote sensing systems and data from Landsat, SPOT (the French *Satellite pour l'Observation de la Terre*), NOAA-10, NOAA-11, and GOES, the team studied the late summer dry-down of the prairie vegetation. The study relates remote sensing measurements to biological productivity and evapotranspiration, laying the groundwork for future climatic and ecological studies including problems of global warming and desertification. The 1989 experiment also provided an opportunity to enlarge the international participation in the experiment to include nine investigators from the Soviet Union.

Global Backscatter Experiment. The Global Backscatter Experiment (GLOBE) aircraft expedition of November 1989 measured the number and size distribution of atmospheric particles, called aerosols, over remote areas of the tropical Pacific and the northern and southern hemispheres. This was accomplished using lidar ("light detection and ranging" laser radar) instruments mounted on a NASA DC-8 research aircraft from Ames Research Center, coordinated with measurements from research aircraft from Japan, Australia, and New Zealand. GLOBE baseline data are contributing to development of NASA's Laser Atmosphere Wind Sounder (LAWS) instrument, scheduled for flight in the EOS program. A second campaign (GLOBE-2) was conducted in May 1990 to conduct similar measurements during a different season.

Loma Prieta Earthquake. NASA's Geodynamics program responded quickly to the Loma Prieta earthquake of October 17, 1989, with fault motion measurements coordinated with the National Geodetic Survey at three mobile very long baseline interferometry (VLBI) sites and with the U.S. Geological Survey at a network of Global Positioning System sites in the region of the San Andreas Fault. Since 1983, the VLBI sites have been monitored at a deformation rate of about 1 millimeter per year. Measurements in the days after the earthquake were designed to monitor immediate post-seismic slip in the epicentral region of the earthquake.

Amazon Deforestation. In 1989, studies of deforestation in the Amazon basin using the vegetation index and thermal data from the NOAA Advanced Very High Resolution Radiometer (AVHRR) were expanded to include the tropical forest regions of Africa and Asia. The goal is to generate coarse-resolution, global-scale estimates of tropical deforestation. AVHRR thermal data are also being used to better understand the role of fire in the deforestation process and to assess its effect on the atmosphere.

Mesoscale Atmospheric Research. During 1989, work progressed on WetNet, a 5-year pilot program examining the role of a remote interactive computer network in an Earth science research environment. WetNet is an important precursor to the EOS Data and Information System (EOSDIS). The primary data source is the Special Sensor Microwave/Imager and is of interest to the atmospheric, oceanographic, cryospheric, and land process communities. The research and data network is designed to enhance scientific analysis and encourage an interdisciplinary approach to the study of the global hydrologic cycle. WetNet entered its operational phase in the summer of 1990.

Publication of Global Data Sets. NASA is in the process of improving archiving and distribution of existing Earth science data sets to the research community. Notable among these efforts was the analysis, archiving, and distribution of Coastal Zone Color Scanner data on optical disks. Other efforts focused on making Earth science data sets more accessible, including conversion to CD-ROM (compact disk-read only memory) and optical disk formats.

Life Sciences

Life Sciences research encompasses basic research and clinical practice, focusing on the development of countermeasures and life support systems for human spaceflight. It also includes the study of exobiology, space medicine, space biology, biospheric research, and controlled ecological life support systems. Ground-based research is conducted in parallel with space flight investigations on space shuttle missions and on Soviet biosatellites. Future flight activities will also occur on extended duration orbiter missions, a recoverable reentry satellite (Lifesat), the Soviet Union's Mir Space Station, and Space Station Freedom.

Spacelab Life Sciences-1. In 1989, preparations were completed for Spacelab Life Sciences-1 (SLS-1), which will be the first space shuttle mission dedicated to life sciences research. It is scheduled to fly in 1991. The 20 flight investigations selected for SLS-1 comprise an integrated package that will address some important questions about how living systems adapt to the microgravity environment of space and how they readapt to Earth's gravity. Full-time crew training began in the spring of 1989 and continued through 1990.

Extended Duration Orbiter Medical Program. Most space shuttle missions flown in 1989 and 1990 carried biomedical investigations that were part of the Extended Duration Orbiter (EDO) Medical Program, a 3-year program intended to ensure the health, safety, and productivity of crew members on EDO space shuttle missions of 16-28 days, especially during landing and egress. Continuing this practice, the International Microgravity Laboratory 1 (IML-1), to be launched in 1991, will fly life sciences experiments from NASA, the European Space Agency, Japan, Canada, and Israel.

Centrifuge Facility. In 1989, Phase B studies were initiated for the Centrifuge Facility, the major life sciences research facility on Space Station Freedom. The centrifuge will enable a wide variety of variable gravity investigations on the station. This program has continued in 1990, with a Phase C/D expected to begin in 1991.

Cosmos. More than 70 NASA-sponsored researchers from 19 States and three foreign countries participated in 31 cooperative life science investigations that were flown on the Soviet Cosmos 2044 biosatellite mission launched in September 1989. Cosmos is an unpiloted recoverable spacecraft that accommodates plant and animal experiments. In 1989, NASA also initiated design studies for Lifesat, a biosatellite that will enable further studies on biological responses to cosmic radiation exposure and microgravity.

Controlled Ecological Life Support Systems. Controlled Ecological Life Support Systems (CELSS) is a program to produce biogenerative life support systems capable of providing food and clean air for space crews. In 1989, a CELSS flight program plan was prepared that will include payloads on the shuttle and Space Station Freedom. In 1990, work progressed on a CELSS breadboard facility at Kennedy Space Center. The large-scale, closed, plant-growth facility became operational and successfully grew wheat, soybeans, and lettuce. At Ames Research Center, a prototype of the "salad machine" for Space Station Freedom was developed and successfully tested.

Space Medicine. NASA's operational medicine program provides medical care to the crew during space missions. This care includes pre- and post-flight medical evaluations, inflight health care, and the maintenance of a database to identify how crews adapt to spaceflight. In 1989, NASA scientists developed a medical toxicology database of information on potential toxins during shuttle missions, including medical treatment options in case of contamination. In the area of countermeasures to space adaptation, a lower body negative pressure device designed to condition crew members against orthostatic intolerance was flown for the first time on STS-32 in 1989.

In the field of human factors and performance research, a biomechanics integrated measurement system, developed at Johnson Space Center, became operational in 1989. In addition, a new laser-based anthropometric mapping system (LAMS) was set up in 1989. The LAMS will be used to design individual seat size and position and location of restraints on shuttle seats.

Telemedicine Spacebridge. One of the most significant life sciences activities in 1989 was the operation of a Telemedicine Spacebridge to Soviet Armenia after the December 1988 earthquake. Via satellite, physicians at NASA and other U.S. organizations provided medical advice and assistance to doctors treating earthquake victims. The Spacebridge was so successful that it was extended to assist in another disaster, the Ufa gas explosion in May.

Space Biology. During March 1989, STS-29 carried a chromosome and plant cell division experiment, called CHROMEX. This dual-purpose experiment tested biotechnology capabilities by growing plants from cloned cell cultures rather than seeds and evaluated the effects of microgravity on cells crucial to the normal development of plant root tips.

Exobiology. The exobiology program concentrates on the pathways of the biogenic elements from the origin of the universe to the evolution of living systems. In 1989 and 1990, work on a space station experiment to collect cosmic dust was begun. This experiment will enable better understanding of biogenic compounds necessary for the origin of life. Exobiology also includes the study of prospects for extraterrestrial life, including intelligent life. The Search for Extraterrestrial Intelligence Microwave Observing Project, to be initiated in 1992, will use ground-based radio telescopes to search for radio signals of extraterrestrial origin. In 1989 and 1990, prototypes of a multichannel spectrum analyzer and a prototype radio surveillance subsystem were installed and tested at the Arecibo Observatory in Puerto Rico, one of the sites that will be used for the project.

Microgravity Science and Applications

The Microgravity Science and Applications program sponsors basic and applied research requiring low gravity conditions. In space, the absence of gravity-induced phenomena, such as buoyancy-driven convection, sedimentation, and hydrostatic pressure, provides a unique opportunity to study many physical processes and materials. Disciplines studied include fluid phenomena, combustion, materials science, and protein crystal growth. In 1989 and 1990, most of the microgravity payloads flown involved protein crystal growth experiments. Work continued on the development of experiments, in other disciplines, which will be flown on upcoming Spacelab flights.

Protein Crystal Growth. The Protein Crystal Growth (PCG) facility was flown aboard STS-29, STS-30, and STS-32 in 1989 and 1990, each completing 60 different experiments using 19 different proteins. The PCG apparatus is planned for several other flights. This experiment will supply information on the scientific methods and commercial potential for growing high quality crystals in microgravity. Protein crystals grown in microgravity are generally larger and more defect-free than crystals grown on Earth. These crystals may be used to help determine the three-dimensional molecular structure of proteins. Such knowledge may yield important insights into biological processes and could potentially be used in applications such as the development of new pharmaceuticals and products that enhance the disease resistance of agricultural crops.

Ground-Based Research. Ground-based research facilities, such as drop towers and aircraft, play an important role in microgravity science investigations. Extensive testing is performed in these facilities before committing to costly space experimentation. In 1989 and 1990, numerous investigations in fluids phenomena, combustion, and materials science were carried out at Lewis Research Center. Studies at Marshall Space Flight Center focused on materials science and containerless processing.

Space Flight Facility Development. In 1989 and 1990, NASA continued to support the development of over 30 experiments to be flown on the shuttle. The hardware being developed includes both investigator-specific and multi-user apparatus. Several of the multi-user facilities are precursors to the six facilities that are planned for the Space Station Freedom. These are the Space Station Furnace Facility, the Modular Containerless Processing Facility, the Advanced Protein Crystal Growth Facility, the Biotechnology Facility, the Modular Combustion Facility, and the Fluid Physics/Dynamics Facility. This is an evolutionary approach to space station utilization which will allow NASA to benefit from the on-orbit experience gained on shuttle flights.

Communications and Information Systems

The communications and information systems program identifies and applies advanced communications and information systems technologies for NASA space science needs, the satellite communications industry, and the public sector.

Advanced Communications Technology Satellite. During 1989 and 1990, NASA continued Advanced Communications Technology Satellite (ACTS) development activities. ACTS is scheduled for a 1992 launch. Delivery of all engineering models and several flight model subsystems and the completion of the ACTS system critical design review occurred. Flight model manufacturing began. Significant progress was also made in working with industry to develop a wide-ranging set of applications-oriented experiments and demonstrations for ACTS.

Mobile Satellite. The mobile satellite program, which is a joint Government/industry endeavor, will provide two-way satellite-assisted communication with cars, trucks, trains, boats, and aircraft within the next 3 to 4 years. During 1989 and 1990, L-band technologies were successfully tested in land/aeronautical mobile applications. American Mobile Satellite Corporation has adopted the concepts developed in the program as its baseline digital service approach. Internationally, the program significantly influenced mobile system design and Canada and Australia have shown interest in the developed mobile equipment. NASA played a lead role in the regulatory activities that led to the securing of the L-band frequency allocation and to the formation of the provider, American Mobile Satellite Corp. ***Search and Rescue.*** NASA's Search and Rescue program is part of COSPAS-SARSAT, an international satellite-based search and rescue system that locates distress beacons from endangered ships and aircraft. The program is a joint venture between the United States, the Soviet Union, Canada, and France. U.S. participation includes efforts by NASA, the National Oceanic and Atmospheric Administration, the Coast Guard, and the Air Force. As of the end of 1990, the COSPAS-SARSAT system was credited with saving a total of more than 1,450 lives. In 1990, NASA also began to focus on plans for the next spaceborne search and rescue system, which will offer new services and improved response times.

Advanced Technology and Systems Development. In 1989-1990, NASA continued development of key technology and systems to address future space communications needs and the increasing demand for communication bandwidths. Technologies and systems under study include the following: optical communications for wide bandwidth, data transmission techniques, robotics, and space-based antennas. The latter will be tested and calibrated on the space station.

Information Systems. The information systems program provides NASA science divisions with access to data archives and directories through the National Space Science Data Center (NSSDC) and, in the future, through the NASA Master Directory. It also provides networking services to the NASA science community through the NASA Internet system and access to high-performance computing facilities. In 1989, NASA initiated work on the NASA Master Directory, a directory with brief, high-level information about available data sets on Earth and space science. This directory provides a starting point for computer-aided searches of data sets. Also in 1989, NASA awarded a contract to Cray Research, Inc. to provide advanced supercomputing facilities to Goddard Space Flight Center and Lewis Research Center. The supercomputers will support the scientific computing needs of Goddard, Lewis, other NASA centers, and NASA-sponsored university research programs. During 1989 and 1990, work also continued on defining the Applied Information Systems Research program. This program is being conducted to apply new information systems research and technology in support of NASA's space science programs. Technologies under study include graphics and visualization, algorithms, data storage, and access methods.

Flight Systems

The flight systems program provides support to the Office of Space Science and Applications through the management of Spacelab missions and planning for science utilization of Space Station Freedom.

Spacelab Flight Program. During 1989 and 1990, extensive preparations were made for several Spacelab flights. Three flights were scheduled for 1990, but were delayed because of a hydrogen leak in the space shuttle. The Astro-1 mission, composed of one x-ray and three ultraviolet telescopes, will make complementary measurements of a variety of stars and galaxies. Astro-1 is scheduled to fly in early FY 1991. Spacelab Life Sciences-1 (SLS-1), a mission dedicated solely to life sciences research, is scheduled to fly in mid 1991. Later in the year, the International Microgravity Laboratory (IML-1) will be flown. IML-1 includes life and microgravity sciences payloads from the United States, Europe, Canada, and Japan. Both SLS-1 and IML-1 are undergoing physical integration at Kennedy Space Center. Preparations are also under way for a 1991 microgravity mission with the Japanese, called Spacelab-J. Also in work are preparations for the Atmospheric Laboratory for Applications and Science (ATLAS) missions, the first of which is scheduled to be flown in 1992. The ATLAS missions will measure the sun's radiation over the 11-year solar cycle, its effect on Earth's upper atmosphere, and the global distribution of key molecular species in the middle atmosphere. Also in 1992, a series of missions dedicated to microgravity research will be initiated with the first flight of the U.S. Microgravity Laboratory (USML).

Space Station Activities. In June 1989, NASA announced the selection of the space station attached payloads. The selections included four investigations in cosmic ray physics, two in astrophysics, one in solar physics, one in communications research, three cosmic dust collection experiments in life sciences and solar system exploration, and three instruments which are part of the Earth Observing System (EOS) program. In 1990, planning for space station utilization continued, with studies focusing on both attached payloads and on life and microgravity science investigations.

Space Transportation

As part of NASA's mission, derived from the President's National Space Policy, the Office of Space Flight is responsible for developing space transportation capabilities, carrying out space flight operations, and planning for men and women to work in space. In addition, the Office continues to support future science and human exploration missions in the solar system and the permanent presence of human beings in space. It has also assisted in the commercialization of space and the privatization of space transportation systems.

The Space Shuttle

Orbiter. The space shuttle's primary purpose is to transport people and cargo into low-Earth orbit (100 to 350 nautical miles altitude). There are presently three active orbiters: Columbia, Discovery and Atlantis. Each orbiter's cargo bay is 15 feet in diameter, 60 feet long and has the baseline capability to carry up to 55,000 pounds. The orbiter can accommodate a flight crew of up to 8 and has a basic mission of 7 days in space. Typical missions range from 4 to 9 days duration, with crews numbering from 5 to 7.

In May 1989, the name "Endeavour"—submitted by school children in NASA's "Name the New Orbiter" contest—was selected for Orbiter Vehicle-105, which is in production. The assembly of the major structural components and integration of systems of OV-105 continued to progress through FY 90. By the end of September 1990 many of the structural components of Endeavour had been mated. Yet to be mated were the forward Reaction Control System, the Orbital Maneuvering System pods, and one payload bay door. Some of the changes made for the new orbiter include a drag chute, a regenerative carbon dioxide removal system, a new waste collection system, and an improved star tracker. The vehicle had begun a full check-out of all of its systems, including power-on testing. Endeavour is scheduled to be delivered to the Kennedy Space Center in May 1991, and to make its first flight in early 1992.

In addition to work on Endeavour, 25 modifications were installed on Columbia (OV-102), 106 installed on Discovery (OV-103), and 47 installed on Atlantis (OV-104) in FY 1990. This was in addition to nearly 300 total improvements incorporated into the three-shuttle fleet in CY 1989. The most significant orbiter improvement in FY 1990 was the initial installation of carbon brakes.

Work also continued in 1989 and 1990 on the Extended Duration Orbiter (EDO) program, which will provide a 16-day mission capability. NASA plans to modify Columbia for this capability and to construct Endeavour such that the option will exist to go beyond a 16-day mission. Modifications that enable extended flight include the addition of a new cryogenic pallet containing four tank sets of oxygen and hydrogen for additional power generation, a regenerative carbon dioxide removal system, an improved waste management system, and increased stowage. Extended missions will be approached incrementally with 10- and 13-day flights prior to STS-63, the first 16-day EDO flight. The 10-day STS-32 mission, which flew from January 9 to January 20, 1990, was the first in a series of flight tests leading to EDO testing.

Space Shuttle Main Engine. The Space Shuttle Main Engine (SSME) program continued its very active test program in 1989 and 1990. Eighty-three ground tests for 35,318 seconds were conducted in support of the development, certification, and flight programs during 1989. During the first 9 calendar months of 1990, 102 tests were conducted for a total of 39,855 seconds. This increased the total since January 1986 to 412 tests for just over 165,000 seconds with a renewed emphasis on reliability, safety, and life enhancements.

The Technology Test Bed Program, which furnishes NASA with critical basic propulsion research and technology capability, was initiated in 1989 at Marshall Space Flight Center in Huntsville, AL. Eleven tests for 800 seconds were successfully conducted on advanced SSME designs. During the first 9 months of 1990, 11 tests were conducted for a total of 1,120 seconds on the advanced SSME designs.

Solid Rocket Booster. The redesigned solid rocket motor (RSRM) is the propulsive element of the solid rocket booster (SRB), which, along with the SSME, powers the space shuttle into space. The RSRM has been operational since completion of a rigorous qualification program. The last qualification static test firing was accomplished in January 1989 and qualified the RSRM for the low-temperature specification limits. A limited development effort continued for improvement of the design, elimination of waivers to flight requirements, and improvements to launch preparation procedures.

Advanced Solid Rocket Motor. In May 1990, NASA awarded contracts to Lockheed Missiles and Space Company for the design, development, test, and evaluation of the Advanced Solid Rocket Motor, as well as for the design and construction of the facility at the abandoned Yellow Creek nuclear facility at Iuka, MS. The new motor will increase safety and reliability, improve the performance of the booster, and increase overall efficiency. The motor design consists of three segments: bolted field joints, welded factory joints, and a carbon integral throat entrance nozzle.

Static testing of the motor will be accomplished at the Stennis Space Center, Bay Saint Louis, MS, while nozzle manufacturing will be conducted at the Michoud Assembly Facility, Slidell, LA and subscale motor testing will take place at the Marshall Space Flight Center, Huntsville, AL. The first flight utilizing the new rocket is targeted for 1996.

1989 and FY 90 Shuttle Missions. NASA successfully completed five space shuttle missions in 1989 and three during the first 9 months of 1990. The missions included STS-29, STS-30, STS-28, STS-34, STS-33, STS-32, STS-36, and STS-31.

STS-29 (Discovery) was a 5-day mission that was launched on March 13, 1989, from Kennedy Space Center, Florida. The primary objective of the flight was to deploy a Tracking and Data Relay Satellite (TDRS-D), which was successfully accomplished on the first day. TDRS-D replaced TDRS-A over the Atlantic Ocean and joined TDRS-C (in geosynchronous orbit over the Pacific Ocean) in completing the constellation of on-orbit satellites for NASA's advanced space communications system. TDRS-A is used as a spare. The TDRS satellites provide communication and data links between Earth and spacecraft such as the space shuttle. The orbiter landed safely at Edwards Air Force Base in California on March 18, 1989.

The second launch of 1989 occurred on May 4,

The Syncom IV-5 communications is seen in orbit over Zaire. It was put into space from Space Shuttle Columbia (STS-32).

aboard Atlantis (STS-30). The primary objective of the 4-day mission was the deployment of the Magellan satellite, which was accomplished successfully about 6 hours after lift-off. Magellan will map up to 90 percent of the surface of Venus with a high degree of resolution. Insertion of Magellan into Venus' orbit was accomplished in August 1990. The landing of Atlantis occurred on May 8, 1989.

The next launch, STS-28, was on August 8, 1989, aboard Columbia. The 5-day flight was a classified DOD mission. After a successful mission, Columbia landed safely at Edwards Air Force Base on August 13.

The STS-28 mission was followed by STS-34 (Atlantis), which was launched on October 18, 1989. The main objective of the STS-34 mission was the deployment of the Galileo satellite, which occurred on Flight Day 1. Galileo is now on its journey to Jupiter to study the planet's atmosphere, satellites, and surrounding magnetosphere. On its 6-year trip to Jupiter, Galileo's trajectory swings around Venus, the sun, and Earth to acquire additional energy from Earth's gravitational forces. The Venus flyby was successfully accomplished in February 1990. The Orbiter's crew ended another successful mission when Atlantis landed on October 23, 1989.

The fifth and last shuttle flight in 1989 was aboard Discovery (STS-33). Discovery lifted off on November 22 and was a classified DOD mission. The mission ended on November 27 with a safe landing at Edwards.

On January 9, 1990, Columbia was launched on a nearly 11-day flight that was highlighted by the deployment of a Navy synchronous communication satellite, Syncom IV-5, for Hughes Communications, and the retrieval of the Long Duration Exposure Facility (LDEF). LDEF is an open-grid structure containing 57 scientific experiments which was launched and deployed aboard Challenger on Mission STS-41C in April 1984. This flight also represented the first in a series of flights leading to extended duration orbiter testing. After successful completion of its mission objectives, Columbia landed safely at Edwards on January 20, 1990.

Shuttle Mission STS-36, a classified DOD payload carried on the orbiter Atlantis, was launched from Kennedy Space Center on February 28, 1990. Atlantis landed safely at Edwards on March 4, 1990.

The 35th flight of the space shuttle, STS-31, was highlighted by the deployment in Earth orbit of the Hubble Space Telescope using the orbiter Discovery. Discovery was launched from Kennedy Space Center on April 24, 1990, with the mission being was completed successfully when Discovery landed safely at Edwards on April 29, 1990.

Hydrogen Leaks. During the launch attempt for the STS-35 (Columbia) mission on May 29, 1990, a hydrogen leak was detected, in excess of limits established to maintain safe operating conditions, scrubbing the mission. Subsequently, during a tanking test of the STS-38 (Atlantis) Shuttle Vehicle, a hydrogen leak was discovered, similar to the temperature and flow rate-dependent leak that grounded STS-35. While investigating the sources of the leaks aboard Columbia and Atlantis, NASA elected to ground the shuttle fleet in the interest of safety. Investigations and repairs lasted throughout the summer of 1990.

In September, NASA was twice again forced to scrub the launch of STS-35 because of recurring hydrogen leaks, which, although not serious enough to cause an explosion, were high enough to exceed NASA's self-imposed limits. At the end of the fiscal year, Columbia was undergoing repairs on Pad A at the Kennedy Space Center while preparations were under way for the October 6 launch of STS-41 (Discovery), carrying the Ulysses interplanetary probe, and STS-38 (Atlantis) was being prepared for a classified DOD payload scheduled for a November 1990 launch.

Future Flights. The NASA "Mixed Fleet Manifest of Shuttle and ELV Flights" was published in January 1990. This publication depicted planned launch dates for the space shuttle and expendable launch vehicles (ELV) that support NASA and NASA-related payloads projected through FY 1996. This schedule called for 8 shuttle flights in 1990, 10 in 1991, 11 in 1992 and 1993, and 12 in each of the remaining years. Unfortunately, the hydrogen leaks resulted in the loss of three scheduled flights in FY 1990. The future shuttle schedule is currently under review. There were 37 ELV launches projected for this period.

Expendable Launch Vehicles

1989 Launches. NASA completed its 30-year management of the Atlas-Centaur and Delta Launch Vehicle programs in 1989 with the successful launch of the Navy FltSatCom satellite on an Atlas-Centaur in September and the Cosmic Background Explorer (COBE) on a Delta in November. NASA also moved into its new role as service provider to the commercial expendable launch vehicle industry by providing NASA facilities and services on a direct cost basis to the commercial launch vehicle industry.

Following the Challenger accident, NASA established a policy of reliance on a mixed fleet of launch vehicles, utilizing both the human-piloted space shuttle and unmanned expendable launch vehicles (ELV) for its space transportation needs. To formalize its decision process on payload flight assignment between the human-piloted shuttle and unmanned ELVs, NASA established the Flight Assignment Board on September 7, 1989. The guiding premise used by the Board is that payloads would be assigned for launch on an ELV unless they required the presence of a human being, another unique capability of the shuttle, or another clearly specified and compelling reason, such as the unavailability of a suitable ELV.

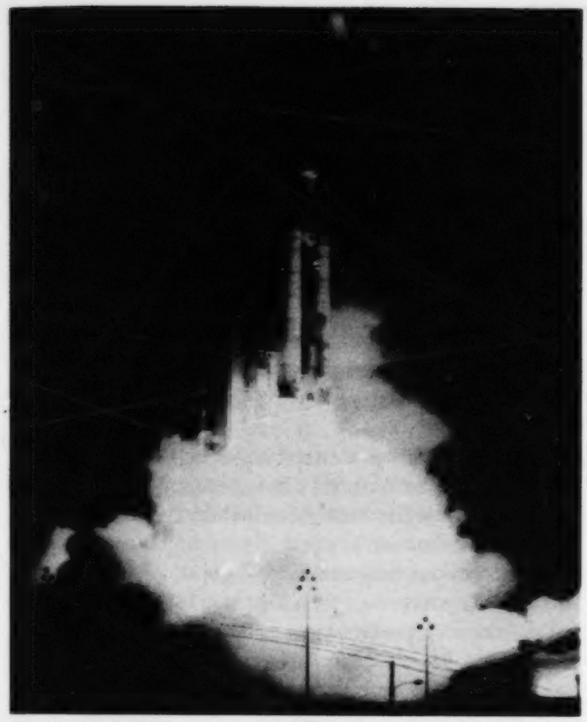
The membership of the Flight Assignment Board includes both Office of Space Flight representatives and the Associate or Deputy Associate Administrators from the NASA community. The Board is chaired by the Associate Administrator for Space Flight. The Board's recommendations are forwarded to the NASA Administrator for review and approval. The Board has met three times, on September 19 and November 14, 1989 and on July 23, 1990. Its significant accomplishments in 1989 included the development and approval of payload assignment criteria and the review of each payload on the June 1989 shuttle manifest against that payload criteria. Implementation of the strategy resulted in the reassignment of four spacecraft from the shuttle to ELVs. All four of the spacecraft—the Roentgen Satellite (ROSAT), the Combined Release and Radiation Effects Satellite (CRRES), the Extreme Ultraviolet Explorer (EUVE) and the Mars Observer—have been launched or are under contract to be launched on ELVs.

The ROSAT mission was launched June 1, 1990 on a Delta II vehicle procured from DOD. The CRRES mission was launched July 25 on a commercial Atlas purchased from General Dynamics. When the EUVE mission is launched in August 1991, it also is scheduled to be aboard a DOD Delta, while the Mars Observer is manifested to fly on a Martin Marietta Commercial Titan, Inc. ELV in 1992. Martin Marietta Commercial Titan, Inc. was awarded a firm fixed-price contract to provide the Titan III launch services for Mars Observer in November 1989. The development of a new Delta 10-foot fairing for the ROSAT mission was completed in 1990 and was utilized for the ROSAT mission.

At its July 23, 1990 meeting, the Flight Assignment Board assigned seven payloads to ELVs, and one, the Advanced X-ray Astrophysics Facility (AXAF), to the shuttle.

Upper Stages

Inertial Upper Stage. The inertial upper stage (IUS) is a USAF-developed vehicle that can transport payloads from low- to high-Earth orbit (geosynchronous) as well as to planetary trajectories. The IUS is launched into space on the space shuttle or a Titan III/IV expendable launch vehicle. During 1989, the shuttle/IUS successfully launched NASA's Magellan, Galileo, and Tracking and Data Relay Satellite (TDRS) D missions. Current plans target shuttle/IUS launches for the Ulysses spacecraft in



First launch of the commercial Titan from Cape Canaveral Air Force Station on December 31, 1989, carrying two communications satellites: Japan's JCSAT 2 and the United Kingdom's Skynet 4A.

October 1990 and a series of additional TDRS missions throughout the early 1990s.

Transfer Orbit Stage. The transfer orbit stage (TOS), developed commercially by Orbital Sciences Corporation, is designed to place payloads into geosynchronous transfer orbit or other high-energy trajectories. It can be carried into space by either the space shuttle or the commercial Titan III. Development, qualification, and mission integration activities continued during 1989 and 1990 for two TOS vehicles to support launch of the Advanced Communications Technology Satellite (ACTS) with a shuttle/TOS in mid-1992, followed by a launch later in 1992 on a Titan III/TOS for the Mars Observer spacecraft.

Spacelab Carrier System

Spacelab, a reusable science observatory/laboratory flown in the shuttle payload bay, was developed by the European Space Agency. It includes a pressurized module that provides a shirtsleeve environment for the crew, as well as a number of unique unpressurized platform pallets for unmanned research activities. NASA has added a number of different experiment carrier systems to complement the original Spacelab hardware. These carrier systems can provide scientists with an in-bay capability to support small experiments up to a full-up life science or micro-gravity module mission.

The NASA mixed fleet manifest shows an extensive use of Spacelab carrier system hardware starting in 1990 and continuing through 1996. Mission planning and integration of flight experiments with Spacelab hardware has been completed for the Astro-1/BBXRT mission. Integration of the flight experiments with the Spacelab hardware for the Spacelab Life Sciences-1, International Microgravity Laboratory-1, Atlas-1, and TSS-1 missions continued throughout FY 1990. The Starlab mission was removed from the shuttle manifest.

In addition, the enhanced pallet successfully completed checkout and acceptance testing in 1990 and flight equipment was received in time to support the Tethered Satellite System (TSS) mission processing activities. The Hitchhiker program continues to play an important role in the flights of Spacelab carrier equipment. As many as 14 Hitchhiker missions are listed on the latest shuttle manifest.

Tethered Satellite System

The Tethered Satellite System (TSS) is a shuttle-based facility for deploying a satellite connected by a tether to the shuttle for distances up to 62 miles. The TSS allows satellites to be deployed into areas previously unreachable and perform unique "in situ" science. The TSS is a cooperative program between NASA and the Italian Space Agency.

In 1990, the deployer and satellite completed system qualification at which time the deployer was delivered to Kennedy Space Center to begin the ground operations phase of shuttle integration. The satellite was placed in storage until it is needed at Kennedy in early FY 1991. Acceptance testing of deployer-based scientific instruments was nearing completion at the end of FY 1990 and is scheduled for delivery early in FY 1991. Shuttle integration activities remained on schedule in support of the planned launch dates.

The 1991 schedule calls for completion of ground processing activities and finalization of mission planning. Shuttle processing will occur consistent with the planned launch date. The first TSS mission is expected to be manifested for flight in 1992.

Advanced Program Development

Advanced Programs activities focus on future space transportation concepts and related operations and on-orbit servicing systems. The scope of Advanced Programs includes concept definition (Phase A), systems definition (Phase B), and advanced development efforts to demonstrate emerging technology for application in existing as well as future transportation systems. The Civil Needs Data Base (CNDB)—a compilation of civil space-mission needs from 1990 to 2010—is a key tool for advanced program planning. Following are some of the studies currently under way in Advanced Program Development:

Shuttle-C. The Shuttle-C is a space shuttle-derived, unmanned, heavy-lift cargo vehicle concept which would have the capability to lift 75-ton payloads into low-Earth orbit. Shuttle-C would utilize existing space shuttle hardware and facilities.

Advanced Launch System. The Advanced Launch System (ALS) program is a joint DOD/NASA program to work toward providing a flexible, robust, reliable, responsive launch system to meet future national launch needs at significantly lower cost than existing systems. The program is responsive to the January 1988 report to Congress signed by President Reagan. While DOD has overall program management responsibility, NASA has specific management responsibility for the advanced development phases and liquid engine development programs.

Next Manned Transportation System. Studies are continuing for the upgrade or eventual replacement of the space shuttle system. The primary focus of the Next Manned Transportation System activity has been on the Shuttle Evolution and Personnel Launch System concepts with only minor activity on the Advanced Manned Launch System concept. The Shuttle Evolution effort investigated a wide range of activities from countering obsolescence, which requires only minor interference to implement, to major modifications requiring block upgrades.

The Space Shuttle Program Office, through its Assured Shuttle Availability Program, initiated activities on near-term problem areas identified by the Shuttle Evolution studies. Hence the Shuttle Evolution program will focus on the far-term improvements and modifications. Personnel Launch System studies addressed both the biconic (low lift/drag) configurations and the lifting body (medium lift/drag) configurations. Contracts were recently initiated to augment the in-house analysis performed over the last year.

Assured Crew Return Vehicle. NASA is continuing studies of an Assured Crew Return Vehicle (ACRV) which would be based at Space Station Freedom to return the crew in case of 1) crew illness or injury; 2) Space Station Freedom catastrophic failure; or 3) space shuttle unavailability to return crew. During 1990, requirements validation and preliminary design studies were completed.

Advanced Upper Stages. The National Space Policy recognizes the need for "in-space transportation systems." The Space Transfer Vehicle (STV) concept, in response to this need, is a high-performance, advanced upper stage to support future science and human exploration missions beyond low-Earth orbit. In 1989 upper-stage concepts and requirements became a focal point of interest and activity because of the President's stated July 20 objectives that included a return to the lunar surface and placing human beings on the planet Mars.

Two parallel 18-month Phase A conceptual design studies were initiated in 1989 to define a STV to meet the needs of the late 1990s and beyond. The STV would have the capability to deliver payloads to geosynchronous Earth orbit, to the moon, and other planetary missions. The STV would thus extend beyond low-Earth orbit the cost effectiveness and operational flexibility provided by the national launch vehicle fleet.

Advanced Space Systems. Formerly Satellite Servicing, the branch name was changed in 1990 to better reflect on-going activities. These activities include advanced hardware development, flight demonstrations, satellite servicing, tether applications, and orbital debris.

Advanced development projects apply existing technology to flight hardware for use on the shuttle, other NASA spacecraft, and satellite servicing. In 1990, work continued on the flight support structure hydrazine coupling and servicing aid, the protoflight superfluid helium coupler, and low force connectors. Flight demonstrations of the Voice Command System and Optical Communications Through the Window were completed for flights on STS-41 and STS-43, respectively. These demonstrations will provide on-orbit experience with voice command of the closed circuit cabin television cameras and of high-data-rate, fiber-optic communications through the aft flight-deck window. The Dexterous End Effector Flight Demonstration will demonstrate the on-orbit use of a force-torque sensor and magnetic end effector. Operational application of this technology could potentially provide significant cost and weight savings for on-orbit assembly and servicing operations. The Superfluid Helium On-Orbit Transfer demonstration planned in late 1992 has already yielded many cryogenic management techniques which are being used on the Advanced X-ray Astrophysics Facility (AXAF), the Space Infrared Telescope Facility (SIRTF), and other spacecraft. The Satellite Servicer System Flight Demonstration Phase B procurement documentation was completed.

Planning has continued for several tether applications flight demonstrations scheduled to fly on Delta launch vehicles in 1992. The Small Expendable Deployer System (SEDS) is a low-cost test bed designed to demonstrate the feasibility of tether operational concepts using existing technology. SEDS I, approved for flight in June 1992, will address severed tether dynamics, confirm basic tether principles, and validate existing models. The mission design for SEDS II will focus on the feasibility of tether-initiated rapid sample return and waste disposal alternatives for possible future space station application. Another tether applications flight demonstration, the Plasma Motor Generator (PMG), is an electrodynamic mission planned for flight in mid-summer 1992. The PMG is designed to demonstrate that a hollow cathode attached to the end of a conductive tether (wire) passing through space plasma will generate electric power.

Orbital Debris. The population density of man-made orbital debris in space at both low-Earth orbits and geostationary-Earth orbits is growing as a direct result of an expanding space launch rate. In recent years spacefaring nations have been increasingly concerned that orbital debris could pose a hazard to future space missions—possibly to unacceptable risk levels early in the 21st century. NASA has devoted a considerable effort over the years toward understanding the orbital debris environment and its trends. Using up-to-date models of the debris environment, hazard analyses have been performed for space programs and appropriate protection measures have been instituted to assure a high probability of safe and reliable space operations.

The NASA space debris population density model was formally reviewed by the NASA Technical Coordination Committee and the Orbital Debris Steering Group. Upon endorsement, the model was accepted as a baseline for the Space Station Freedom design and hazard analyses. The model will be updated periodically as new data from debris measurements and hypervelocity testing become available.

During 1989, NASA held meetings with ESA representatives to share information on the debris issue and discussed the issues with the space agencies of Japan, Canada, and the Soviet Union. ESA has established an Orbital Debris Working Group and an agreement has been enacted between NASA and ESA to exchange technical data and study results. Additionally, in 1989, a cooperative agreement was established between NASA and BMFT, the West German government research and technology agency.

In an attempt to expand the communication network to more than bilateral, one-on-one discussions, NASA organized an AIAA-administered international orbital debris conference in April 1990. There was strong participation by both the United States and the international members of the debris community with a good exchange of the latest and planned research programs. The conference conclusions highlighted the need for better communications and data exchanges, the need for improved models of debris population density, and an endorsement of the position that it is premature to consider establishing regulatory guidelines until further studies and tests have been completed.

Space Station Freedom

In President Bush's first budget, submitted to Congress in February 1989, he affirmed the importance of space and the space station to our Nation's future:

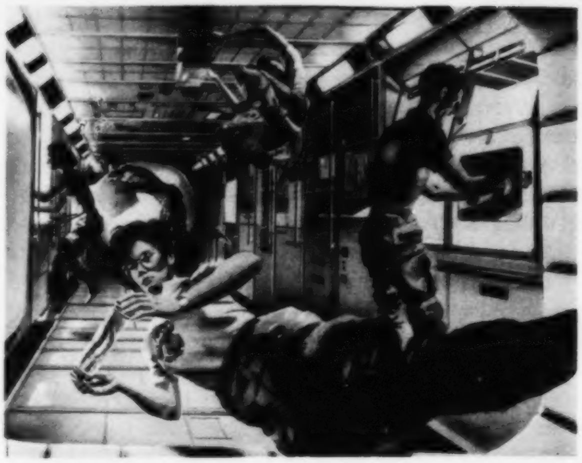
"Our commitment to space is important to our national security, continued economic growth, and our quality of life here on Earth. Space is where important scientific and commercial breakthroughs of the future may be made, where medicines of the future may be manufactured, where some of our descendants may even make their living. . . . Space Station Freedom, planned for operation in the mid-1990s, is a keystone of the Nation's space policy."

The space station is now 1 year closer to the first element launch, scheduled for March 1995. Significant progress was made in the development of all space station systems and elements. This progress is reflected not only in more complete designs of space station components and assemblies but also by the fabrication of hundreds of pieces of pre-flight development hardware including breadboards, testbeds, technology demonstration hardware, and other pre-flight development test articles.

The Space Station program continues to move forward with the design and development activities. Review of the integrated program preliminary design is planned for December 1990. Following this review, engineers at each Work Package will continue detailed design based on the approved preliminary design. These final, detailed designs will be used for manufacture of the various flight hardware elements of the space station. Thus, completing the preliminary designs is a crucial and significant milestone in the Space Station program.

The next milestone for design and development efforts will be the critical design review planned for 1992. This will begin the program's transition to large-scale fabrication of flight hardware.

With respect to management, the Level I organization at NASA Headquarters has been modified as a result of merging the Office of Space Station with the Office of Space Flight. This merger was undertaken to ensure that NASA's human space flight programs are completely coordinated. The program management has been strengthened by the addition of some of NASA's most experienced managers from the Space Shuttle program.

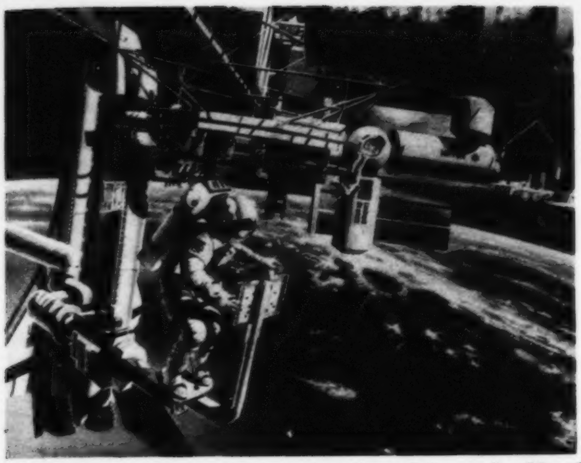


An artist's concept of a typical work day onboard Space Station Freedom, with five of the international crew of eight at work in the U.S. laboratory module.

Program Accomplishments

The contractors' design efforts were complemented by the fabrication and test of various pieces of development hardware to supply data needed to support design efforts for space station systems and elements. Considerable progress was made on such elements as the habitation module, the truss structure, mobile transporter, power and propulsion systems, and Attached Payloads Accommodation Equipment. Engineering hardware for the environmental control system has been tested, and technologies have been selected for use in the air and water recovery loops. In addition, NASA began to design ground facilities to support space station operations, awarded hardware contracts for the Flight Telerobotics System and core electronics, and initiated long-lead procurements of some elements.

In addition to hardware progress, major program accomplishments include the progress that the Preliminary Design Review Resources Board has made toward reducing space station weight and power requirements. EVA requirements have also been addressed, and significant reductions in projected EVA requirements have been made.



An artist's concept of an exterior view of the underside of Space Station Freedom which will serve as a platform for several Earth-viewing experiments. Also shown is an astronaut in the foreground being moved on the end of Canada's Mobile Servicing Center manipulator arm, the Japanese Experiment Module on the right, and the space shuttle on the left.

International

NASA continued to work closely with space station's international partners—Europe, Canada, and Japan. Several coordinated studies and reviews were completed, and all the partners are participating in the Space Station program level Integrated Systems Preliminary Design Review. Other multilateral activities included the first government-level Space Station Cooperation Review, held at the State Department in the summer of 1989. The Canadian Space Agency completed its preliminary design review as well as an interim design review, and the European Space Agency and the Science and Technology Agency of Japan are working toward their preliminary design reviews in the next 2 years. ESA also initiated a study of Man-Tended Free Flyer servicing requirements and selected a polar platform design.

An agreement was made among all four partners on an International Standard Payload Rack that will facilitate commonality and payload interchangeability. This agreement is indicative of the progress that the partners have made toward the design of integrated, common systems.

Several joint program reviews were held between NASA and each of the partners for issue resolution and to discuss major program milestones.

Operations and Utilization

During FY 1990, major progress was made in defining the Operations/Utilization Capability Development requirements. Program activities associated with Operations/Utilization Capability Development include building and implementing all ground infrastructure essential to operate, use, and support the manned base over its 30-year or more lifetime.

Tactical- and execution-level Function Control Documents, which define the functions required of the ground systems of each NASA center and international partner ground systems, have undergone two multilateral reviews. Baselining these documents will be part of the Integrated Systems Preliminary Design Review. A major operations support contract was awarded and ground was broken for the Johnson Space Center Neutral Buoyancy Laboratory, a facility to enable development and verification of space station assembly concepts.

In the area of utilization, significant progress was made in assisting user communities, including Government, academic, and commercial, to understand the unique capabilities of Space Station Freedom. Several utilization documents are nearing completion including "A Space Station Freedom Users Guide," "An Introduction to Space Station Freedom," and a brochure describing the utilization disciplines on the space station. Two major workshops were also held with potential commercial users to highlight Space Station Freedom's utilization potential and receive feedback from the commercial community on interests and needs.

A mechanism to collect and integrate user requirements for manifesting was identified. The first multilateral utilization study was completed, which provided an assessment of the user accommodations of the Freedom design. A follow-on activity of the multilateral utilization study has been initiated, which is simulating the strategic and tactical integration planning process. A prototype user-requirements database was developed which can electronically transfer information between the partner's database and the United States.

We have begun consulting with the partners on space station crew selection requirements. Working groups have been established with participation from the partners to finalize the Space Station Freedom Astronaut Selection Criteria.

Evolution

Advanced system studies in FY 1990 identified preliminary reference configurations for evolution of the baseline space station, and also recommended associated design provisions ("hooks and scars") and technology requirements to protect options for future evolution. The Evolution Engineering Data Book has been completed and will guide designers as they make near-term decisions with long-term implications. Other major activities included the analysis of proposed revisions to the baseline space station configuration and a study of space station accommodation requirements for the Space Exploration Initiative.

Space Station Freedom might perform several functions to support the Space Exploration Initiative. First, Space Station Freedom can enable some research and technology activities required to support this initiative, many of which need to be conducted in the space environment. Second, it could serve as a transportation node for assembling, testing, launching, and recovering lunar and Mars vehicles. Space Station Freedom could also supply some crew support, data management and communication systems, and logistics services to accomplish these activities.

Conclusion

Space Station Freedom is an investment in the future and an important step toward advancing American leadership in space. In the words of President Bush, it will serve as "a new bridge between the worlds, and an investment in the growth, prosperity, and technological superiority of our Nation."

The Space Station program has made substantial progress in FY 1990. Preliminary designs will soon be replaced by detailed designs, to be followed by construction of component hardware.

Space Station Freedom is a cornerstone of our civil space policy and a symbol of our commitment to international leadership and cooperation in the peaceful exploration of space. By building Space Station Freedom, the United States will affirm its preeminent role as the leader in space exploration and achievement.

Safety and Mission Quality

With more than 85 percent of NASA's budget funding various industry contracts, the Quality and Productivity Improvements Program Office, established in 1982, has implemented new plans and increased ongoing efforts to ensure continuous improvements throughout the NASA/contractor team.

The Sixth Annual NASA/Contractors Conference, held in Huntsville, AL, in October 1989 drew over 800 people representing more than 200 organization/business units from Government and the aerospace industry. The conference covered a broad range of topics including service industry techniques, ideas to improve the quality of the workplace, exploring Government initiatives regarding quality improvement, customer satisfaction, and improving technology management.

During the Sixth Annual NASA/Contractors Conference, NASA announced the Lockheed Engineering and Sciences Company, Houston, TX, was the recipient of the 1989 NASA Excellence Award for Quality and Productivity. Lockheed was selected from among eight highly qualified finalists. The administrator added a small business category for its NASA Excellence Award for 1990 to further encourage its contractors to use quality principles and tools.

NASA has put in practice the principles and philosophy of "total quality management" with NASA employee teams, suggestion programs, conferences, and awards. NASA's total quality management initiatives are designed to foster improved quality and productivity among both the civil servant and contractor workforces. NASA's Lewis Research Center, in Cleveland, OH, and Johnson Space Center, in Houston, TX, were named quality improvement prototypes by the Office of Management and Budget—as such, they are models for other Federal agencies.

Office of Commercial Programs

As 1989 marked the 20th anniversary of the first lunar landing, it also reminded us that our Nation's investment in space enterprise has rendered countless benefits to its citizens. Technological advances have improved the quality of our lives and have had positive impacts on our national economy. Through cooperative efforts with U.S. industry to commercially develop space and accelerate the commercial application of space technologies, NASA continues to seek expanded economic returns from our public investment.

Significant progress was made in defining an overall program for the commercial development of space. NASA's Office of Commercial Programs categorized and scoped the different types of commercial space activities, assessed the unique requirements and issues affecting the growth of each, and developed mechanisms to carry out a comprehensive program.

Establishing a Strategic Vision

Space harbors valuable resources that represent an underdeveloped economic frontier. With strong foreign competition in space-related industries, a strategic plan for U.S. commercial space development is clearly needed. In 1989, several key initiatives were carried out by NASA that will culminate in a strategic plan founded in national space policy goals.

Both the Commercial Programs Advisory Committee, in its formal report entitled "Charting the Course: U.S. Space Enterprise and Space Industrial Competitiveness," and the American Institute of Aeronautics and Astronautics, in a study document entitled "Issues in Strategic Planning for Commercial Space Growth," addressed critical policy issues affecting commercial space development and the roles of Government, industry, and academia in space commerce.

Based upon these major efforts, NASA is developing a strategic plan based on three key goals: 1) actively fostering the development of space-related markets; 2) improving availability of and access to transportation and infrastructure to support emerging markets and new ventures; and 3) using NASA resources to support the development and growth of successful commercial space ventures.

In August 1990, NASA announced its intentions to establish a Space Commerce Steering Group, composed of senior NASA officials, to provide a high-level overview of commercial applications of space technology. The group will draw on expertise and support from the Commercial Programs Advisory Committee in directing future coherent, consistent NASA policies related to space commerce.

Industrial Research and Development in Space

The return to flight of the space shuttle triggered a resurgence of industrial research and development activity in FY 1989. Most of the commercial interest was directed toward focused or applied research in the behavior and processing of materials in the microgravity environment of space.

NASA's 16 Centers for the Commercial Development of Space (CCDS) are consortia of university, industry, and Government conducting early research and testing of potential commercial products or services. An important goal of the program is to encourage the active involvement of U.S. firms in commercial space development. Over the last year, the number of corporations affiliated with the CCDSs has grown to 175, and their share of financial contributions has continued to increase. The ratio of private-to-Government support of the CCDS is now approximately 3-to-1.

In the last year the CCDS have made significant accomplishments in materials processing in space. Microgravity processing has resulted in superior protein crystal formations that can advance medical research in cancer, AIDS, and other serious diseases; well-ordered, porous, thin, film membranes that can be used in filtration, dialysis, and other separations-industry applications; and high-purity indium for use in the production of advanced electronic devices. Thus far, the CCDSs have been awarded 18 patents for their research work and have many more pending approval.

In 1989, the first CCDS technology and corporate spinoffs took place. Maxwell Laboratories, of San Diego, CA, in collaboration with the Center for Commercial Development of Space Power, developed a stronger, more efficient power supply. And BioCryst, a pharmaceutical firm in Birmingham, AL, was incorporated to commercially market the technologies being developed by the Center for Macromolecular Crystallography.

In an effort to match space transportation and support capabilities with the anticipated growth in materials processing requirements, NASA initiated grant funding for a commercial sounding rocket program. The

March 29, 1989, launch of materials processing experiments developed by a NASA CCDS aboard Space Services Incorporated's Starfire rocket represented the first Federally licensed commercial launch. Two subsequent launches of the Starfire rocket took place in November 1989 and May 1990.

NASA recently announced support for plans to develop the Commercial Experiment Transporter (COMET), a system for launching and recovering spaceborne experiments. The CCDS, which initiated the program, will be totally responsible for system design, fabrication, test, and operations. Industry will provide key hardware and services for each segment of the COMET development and operations.

As part of the CCDS goal of providing cost-effective hardware for conducting experiments in space, the Wake Shield facility is being developed by the Space Vacuum Epitaxy Center in Houston, TX, to permit research in a high, ultra-pure vacuum during space shuttle flights.

Cooperative Agreements

In 1989 and FY 1990, NASA expanded its partnership with U.S. industry through the signing of cooperative agreements providing technical assistance and access to launch facilities and services to support industrial space research, commercial space transportation, and the private development of space infrastructure and services. NASA uses these and other innovative agreements to help reduce the risks associated with commercial development of space.

The Coca-Cola Company signed a Memorandum of Understanding (MOU) with NASA in June 1989, to support the firm's investigation of fluid dynamics, gas-liquid separation, and metering technologies in space. More recently, in September 1990, NASA signed an MOU with Technology and Administrative Services Corporation for the exchange of information on closed-environment system technology.

NASA signed agreements with Conatec Incorporated, in May 1989, and Orbital Sciences Corporation, in July 1990, to support the development of the commercial expendable launch vehicle industry. In February 1990, Global Outpost Incorporated and the University Corporation for Atmospheric Research independently negotiated agreements with NASA for use of the space shuttle's expended external tanks in suborbital experiments.

Building U.S. Competitiveness Through Technology Transfer

During 1989, NASA continued to open new avenues for the transfer of NASA-developed technologies to the public and private sectors. By participating in a number of new cooperative ventures and implementing new initiatives, NASA's nationwide technology transfer network has been further strengthened and expanded. With the addition of eight new affiliates, the network now extends into 41 States across the country.

Major agreements have been signed by NASA and individual States to enhance technology transfer efforts and to have a favorable impact on the States' economies. One such cooperative venture between NASA and the State of California is expected to help advance research in superconductivity. An agreement with the Center for New West, a nonprofit policy research organization, will link members and affiliates in 18 western States with the NASA technology network.

NASA is also working closely with the Department of the Navy to assist in developing a Navy Technology Transfer Center. The Navy is interested in identifying state-of-the-art technology available in industry, academia, and other Government agencies and bringing it into Navy repair and maintenance facilities to solve critical problems.

NASA's direct support of technology application efforts in 1989 helped to advance a range of industries from medicine to transportation. There are 73 joint-sponsored application projects currently being conducted at nine NASA field installations.

Application projects are geared toward the solution of public- and private-sector problems that have been identified by user organizations. The projects are cooperative efforts, with partial funding and complete marketing of the resulting technology provided by the industrial partner.

One technology resulting from an applications project has led to major advances in diabetes control. Known as the Rechargeable Physiologic Sensor, the implantable device monitors glucose levels for insulin-dependent diabetics.

Two new technological developments have also emerged from the research activities of NASA's Industrial Application Centers: a combination worklight/general-purpose flashlight called TANDEM, and a "fail safe" screen pop-out system designed to protect the structural elements of screened enclosures used in hurricane-prone regions.

In 1989, the economic impact of NASA technology transfer was assessed by the Chapman Research Group Incorporated, in a report entitled "An Exploration of Benefits from NASA 'Spinoffs.'" The study found that technology applications have generated $21.3 billion in sales of new or improved products and nearly $356 million in Federal income tax revenues. Additionally, 352,000 jobs were projected to have been created or retained because of the increased revenues attributed to these spinoffs.

Small Business Innovation Research Program

Small Business Innovation Research (SBIR) program objectives include stimulating technological innovation in the private sector, strengthening the role of small businesses in Federal research and development (R&D) programs, fostering and encouraging greater participation of minority and disadvantaged persons in technological innovation, and increasing private-sector commercial development of innovations derived from Federal R&D.

A 1989 survey conducted by NASA, with which the General Accounting Office concurred, indicated that the program had become a highly regarded element of NASA's overall R&D activities. The survey found that the quality of research conducted in SBIR projects was as high or higher than comparable research funded through other R&D means. The results of more than half the SBIR projects reviewed have already been incorporated, or will soon be incorporated, into NASA mission programs.

NASA's assessment also found that at least one-fourth of the projects had already resulted in commercial products or enterprises by the small businesses, and that a substantial number of minority and disadvantaged firms had won SBIR contracts for high-technology projects.

In an effort to anticipate and encourage winning companies to develop the commercial potential of SBIR results, the SBIR Office has initiated a program to follow and report on projects as they proceed.

NASA's Office of Commercial Programs has provided a focus for action to stimulate and assist an expanded involvement by the U.S. private sector in civil space activities. Strengthened by a rich tradition of NASA cooperation with industry, the program has supported high-technology commercial space ventures, the commercial application of existing aeronautics and space technology, and greater access by commercial firms to NASA capabilities and services.

The challenge remaining has been to organize these efforts into a program that develops commercial space markets, low-cost commercial space transportation systems, and commercial space infrastructure to strengthen U.S. industrial competitiveness.

Space Operations

The Space Operations program continues to provide spacecraft operations and control centers; ground and space communications; data acquisition and processing; flight dynamics and trajectory analyses; spacecraft tracking and applied research; and development of new technology.

Space Network

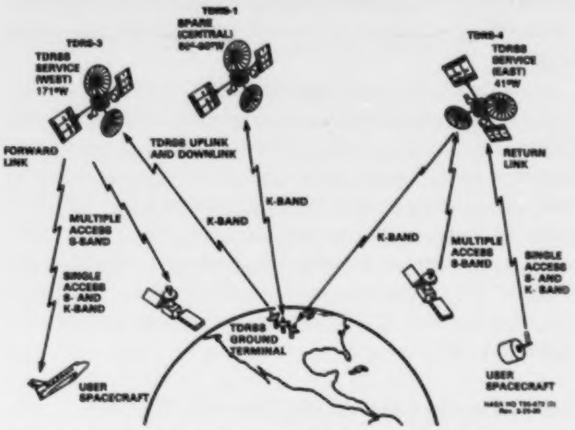
In 1989, a key milestone was achieved in the evolution of NASA's Space Network when the Tracking and Data Relay Satellite System (TDRSS) became fully operational in geosynchronous orbit, providing support to low-Earth-orbit missions. This represented a major advancement in space communications. The operational space network provided communication and tracking for over 85 percent of each spacecraft orbit around Earth. With the previous ground tracking network, coverage was limited to about 15 percent of a spacecraft orbit. This event brought to reality the long-awaited transition from a ground-based tracking network to a space-based tracking capability for low-Earth orbital missions. The operational Space Network allowed NASA to execute its plans to close or transfer to other agencies the four ground stations located at Ascension Island, Guam, Hawaii, and Santiago, Chile. Many stations were closed earlier in anticipation of the Space Network becoming operational.

The Second TDRSS Ground Terminal (STGT) was dedicated in January 1990. This new facility at White Sands, NM will eliminate a critical single point of failure and add the necessary capability to operate additional TDRS in the future when user spacecraft demand increases. The completion of this building, together with the construction of the associated antenna foundations, made the facility ready for the introduction of the new ground communications equipment. Contractors were selected and have initiated preliminary design (Phase B) studies for the Advanced Tracking and Data Relay Satellite System (ATDRSS) program. The purpose of the ATDRSS program is to maintain and augment the current TDRS system when available satellite resources are expended in the latter part of the decade, meet evolving needs for satellite tracking and communications through the year 2012, and introduce new technology to reduce system life-cycle cost.

Ground Networks

The Ground Network is comprised of the Spaceflight Tracking and Data Network, the Deep Space Network (DSN), and the Aeronautics, Balloon, and Sounding Rocket programs. They have continued to provide tracking and data acquisition support services to all NASA science and engineering missions for vehicles in high-Earth orbit, in deep space, and for sub-orbital flights.

In August 1989 the DSN performed a nearly flawless operation in the Voyager 2 encounter with Neptune, which was a culmination of a 12-year mission to tour the four giant outer planets. The DSN was augmented by non-NASA facilities in Australia, Japan, and New Mexico for this encounter. Because of the need to overcome the great distance involved, more receiving capability was created for the Voyager 2 Neptune encounter during the summer of 1989 in order to increase the number of pictures to be equivalent to that taken at Uranus in 1988. The Australian government provided the Parkes Radio Telescope to be used in combination with the DSN site at Canberra. The Japanese Deep Space Station at Usuda was used during the closest approach to Neptune on August 25 to provide radio science data as Voyager 2 passed behind Neptune and its moon, Triton. The National Science Foundation's Very Large Array (VLA) in Socorro, NM, was also employed for the encounter. The VLA consists of twenty-seven 25-meter antennas, whose signals were combined into one and then further combined with those at the DSN site in Goldstone. Also, in 1989, the DSN successfully supported the launches of Magellan and Galileo spacecraft. Magellan will study the planet Venus, and Galileo will probe the atmosphere of Jupiter and tour its family of satellites.



Tracking and Data Relay Satellite System (TDRSS).

In 1990, the Ground Networks provided launch and landing support for the shuttle missions and tracking and data acquisition support was provided to the Magellan spacecraft on its mission to map the surface of Venus; to Galileo on its journey to Jupiter and Titan; and to Ulysses on its mission to the sun. Data acquisition and communications support was also provided to flight research projects and atmospheric research activities. Telecommunications support was successfully provided to NASA's interplanetary and planetary spaceflight missions. These missions are gathering considerable data on Venus and the outer reaches of the solar system. Foreign missions, some of which were cooperative, were also supported to collect data from Earth and the moon.

The Spaceflight Tracking and Data Network comprises three operational ground stations, their primary function is to provide launch and landing services for both human-piloted and unmanned spacecraft. In 1989 the STDN was further reduced from a worldwide network of seven stations which were primarily used to provide tracking and data acquisition for low-Earth-orbit spacecraft. The successful implementation and operation of the TDRSS Space Network permitted the closure or transfer to other agencies of the four ground stations at Hawaii, Guam, Ascension Island, and Santiago, Chile. Merritt Island, FL and Bermuda have been retained to provide essential launch and landing support. The Dakar, Senegal station is used as a TDRS back-up for emergency communications during shuttle launches.

Communications and Data Systems

The elements of the Communications and Data Systems program form the vital link between the data acquisition stations and the scientific users and project facilities. The basic elements are the following: two communication systems, spacecraft mission control centers, and data processing facilities. The program also includes national and international coordination of the electromagnetic-frequency spectrum allocation process and usage.

The Communications Program continued to provide two agency-wide communications systems, NASA Communications Network (NASCOM) and Program Support Communications Network. These global systems interconnect NASA's foreign and domestic tracking and data acquisition stations; NASA's launch complexes, mission and network control centers; and NASA's field centers, major contractors, investigator sites, and international partners.

The Mission Control program continued to provide the control and performance analyses of NASA's unmanned Earth-orbiting spacecraft. These control facilities generate the instructions for the spacecraft to make observations and measurements, monitor spacecraft status, and maneuver the spacecraft. In 1990, the mission control and data processing facilities supported the launch and early orbit checkout of Cosmic Background Explorer and Hubble Space Telescope. These facilities also provided routine mission operations for six on-orbit spacecraft. The productive Solar Maximum Mission operations were concluded. Also two major data processing facilities were completed: the Generic Time Division Multiplexer Facility, which will provide support to satellites that use time-division telemetry, and the Packet Processing (PACOR) Facility, which will support packet telemetry satellites. The Spacelab Data Processing Facility is ready to support the Astro/Broadband X-ray Telescope (BBXRT) mission in 1991.

Definition studies and preliminary design for the Customer and Data Operations System (CDOS) were completed in June 1990 by two independent contractors. These studies provide the basis for a preliminary system architecture. CDOS will provide the data handling, processing, and distribution functions for the Space Station Freedom and Earth Observing System era.

Advanced Systems

The Advanced Systems Program continued to focus on assessing and employing technological advances in telecommunications, electronic micro-circuitry, and computer sciences. These efforts are essential for the cost-effective application of new technology to meet future mission requirements. The work on low-cost, high-electron-mobility transistor amplifiers allowed use in 1989 for the full capability of the National Science Foundation's Very Large Array for receiving telemetry during the Voyager encounter with Neptune. Without this capability, cost and reliability issues would have prevented the use of the full array and significantly reduced the data obtained in the Neptune encounter.

Aeronautics Research and Technology

Within NASA, the Office of Aeronautics, Exploration, and Technology is responsible for the planning, advocacy, direction, execution, and evaluation of projects and research activities concerned with aeronautics research and technology. NASA's strategy for aeronautics research and technology represents a response to the challenges to the Nation's aviation leadership and the opportunities for technological advances identified by the Executive Office of the White House, Office of Science and Technology Policy's 1985 and 1987 reports. Together these reports outlined national goals in the trans-atmospheric, supersonic, and subsonic flight regimes to focus high-leverage technology developments and concluded with a broad strategy for revitalizing the Nation's capacities for innovation in aeronautical research and technology. To implement this strategy NASA is pursuing the following six key thrusts:

- Subsonic transports—develop high-leverage technologies to ensure future competitiveness of U.S. subsonic aircraft and to enhance the safety and productivity of the National Airspace System;
- High-speed civil transport—resolve the critical environmental issues and establish the technology foundation for future decisions on economical, high-speed air transportation;
- High-performance aircraft—provide technology options for revolutionary new capabilities in future high-performance fixed and rotary wing aircraft;

- Hypersonics/transatmospherics—develop critical technologies to support development of future hypersonic and transatmospheric vehicles;
- Fundamental technology base—pioneer the development of the fundamental knowledge base for the design and operation of advanced aerospace systems; and
- Critical national facilities—develop, maintain, and operate critical national facilities for aeronautical research and for support of industry, DOD, and other NASA programs.

The NASA aeronautics program itself is conducted at NASA research centers located in California, Ohio, and Virginia. Each center has unique facilities and research staff expertise that provide a significant national resource for the pursuit of new advancements in aeronautical technology. All three centers conduct extensive in-house research utilizing special facilities and equipment. In addition, each center conducts research in close coordination with other Government agencies, universities, and industry.

The Ames Research Center, in Moffett Field, CA, utilizes its unique capabilities in computational fluid dynamics and computer science applications to focus on the development of new analytical methods. The Center also has advanced aerodynamic testing and flight simulation facilities for validating analytical methods and conducting research investigations of both small- and large-scale aeronautical vehicle configurations. Ames also conducts human factors, aircraft and air traffic control automation, flight dynamics, and guidance and digital controls research. The extensive flight test research capability of the Ames/Dryden Flight Research Facility complements Ames' ground-test capability. Key systems-technology areas include propulsion/airframe integration, powered lift technology, and rotorcraft aeromechanics.

Propulsion is the primary focus of the Lewis Research Center, located in Cleveland, OH. The Center's research and technology expertise has been divided into four main thrusts for strategic planning purposes: aeropropulsion, space propulsion, space power, and space science and applications. The objective of the aeropropulsion thrust is to advance and strengthen aeropropulsion technology that will contribute significantly to the development of U.S. civil and military aircraft.

The Langley Research Center, in Hampton, VA, pursues research in fundamental aerodynamics and fluid mechanics, computer science, unsteady aerodynamics, human factors, and aeroelasticity. Aerodynamic testing to support the research in each of these areas is a major focus of the Center. In addition, the Center is a leader in structures and materials research, with a primary focus on the development and validation of structural analysis methods and research in airframe metallic and composite materials. Langley also conducts fundamental research on fault-tolerant electronic systems and flight control. Other research areas include simulation and evaluation of advanced operational aircraft systems, acoustics and noise reduction, and propulsion/airframe integration.

Disciplinary Research and Technology

NASA's disciplinary research is aimed at establishing and maintaining a solid foundation of technology in the traditional areas of aerodynamics, propulsion, materials and structures, information sciences and human factors, and flight systems and safety. Research objectives include development and validation of computational methods for analysis and prediction of complex external and internal flows, structural mechanics, control theories and their interactions; development of design and validation methods for highly reliable, integrated, and interactive control of aerodynamics, structures, and propulsion systems; development of human-error-tolerant, computer-aided piloting systems; development of design methodologies and life prediction modeling techniques for advanced high-temperature materials; and development of a solid research base to enable new innovative concepts.

Aerodynamics

The NASA aerodynamics effort provides the technology base upon which vehicle advancements can be made throughout all speed regimes and aerospace vehicle classes. Disciplinary research in aerodynamics is structured in a program of closely integrated efforts in theoretical analyses, numerical simulation, wind-tunnel testing, instrumentation development, and selected flight-research projects.

Computational Fluid Dynamics. A major research emphasis in aerodynamics is development of Computational Fluid Dynamics (CFD) methods and codes to advance understanding and prediction of complex aerodynamic phenomena. Research includes flow diagnostics using Navier-Stokes and Euler computations to improve the understanding of detailed mechanisms associated with induced drag. CFD is continuing to provide powerful analytical, simulation, and predictive tools to describe the complex physics of aerodynamic flow. Recent accomplishments using CFD to study aerodynamic flow include the use of Reynolds-averaged, Navier-Stokes codes and a high-resolution grid to analyze vortex breakdown over a double delta wing. In addition, the Navier-Stokes solution for a flat-plate delta wing with two simulated jets issuing from the underside of the wing has compared favorably with experimental results. In other studies, direct numerical simulation of flow in a channel has produced valuable insights into the physical mechanisms which lead to the development of turbulent flows.

Supersonic Riblets. Modification of aerodynamic surfaces with streamwise grooves, called riblets, has been shown to reduce turbulent skin friction. At subsonic speeds riblets produce up to a 10-percent reduction in drag across the Reynolds number range. This past year an F-104 aircraft with a flight-test fixture mounted on the underside was used to test riblets at supersonic speeds. A 5- to 10-percent reduction in skin friction was observed at Mach numbers up to 1.8 and altitudes up to 45,000 feet. The data suggest that passive concepts such as riblets could provide reduced fuel consumption and increased range for a number of commercial and military aircraft types.

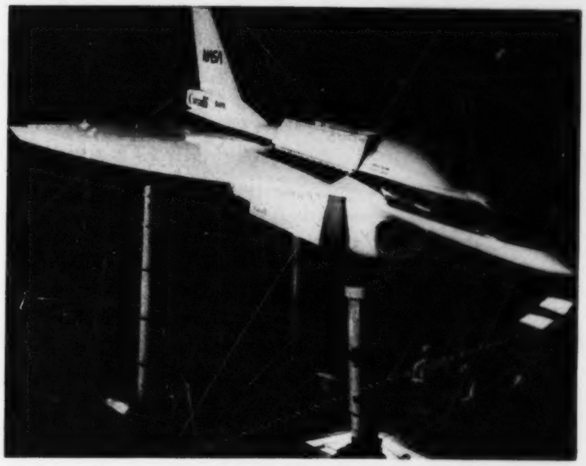
Unsteady Aerodynamic Simulation. This type of computational tool uses the capability of CFD to simulate flows about realistic aerodynamic bodies in relative motion. The computation is done using a time-dependent Navier-Stokes solver and a dynamic overlapping grid scheme and is applied to a wide range of problems, including space shuttle and Shuttle-C solid-rocket-booster and external-tank separation sequences, separation of payloads and spent external fuel tanks from high-performance aircraft, staging sequences of multistage launch vehicles, ground/aircraft interaction during takeoff and landing of short-take-off-and-vertical-landing (STOVL) aircraft, and release sequence of the Pegasus satellite launch vehicle.

Hybrid Laminar Flow Control Flight Experiment. Hybrid Laminar Flow Control (HLFC) is a recently developed technique for maintaining low-drag flow on an aircraft wing by air suction near the leading edge and special wing-surface contouring. Research has suggested that 8- to 10-percent reductions in aircraft drag can be realized. In 1990 an HLFC section was developed for a B-757 transport aircraft wing and flight tested in a cooperative research program with Boeing and the U.S. Air Force. The experiment established that HLFC operation for the wing mid-span is plausible. Laminar flow was observed back to 65 percent chord.

STOVL E-7A Tests. The E-7A program is part of an overall NASA effort in the development of short-take-off-and-vertical-landing (STOVL) technology. In 1989 the full-scale powered model of an E-7A aircraft was tested in both the 40-x-80-foot and the 80-x-120-foot test sections of the National Full-Scale Aerodynamics Complex at the Ames Research Center. The primary objectives of these tests were to determine augmentation ratios and accelerating and decelerating performance margins. Tests of the model at simulated forward flight velocities ranging from 25 to 120 knots demonstrated that the aircraft has adequate acceleration and deceleration performance, enabling it to transition from hover to forward flight and back to hover in level flight. These efforts are expected to lead to a STOVL flight demonstration program enabling the development and deployment of a new class of supersonic STOVL combat aircraft in the United States.

Propulsion

Advanced propulsion technology is the key to realizing major improvements in many new aeronautical vehicle concepts. Propulsion system technology is built upon a solid base of focused discipline research in areas of Internal Fluid Mechanics (IFM), high-temperature materials, advanced control concepts, and new instrumentation techniques. Discipline research in IFM provides analytical tools necessary for describing complex flows in turbomachinery, high-speed inlets, exhaust nozzles



Model of the E-7A Short-Take-Off-and-Vertical-Landing Aircraft in a Wind Tunnel at Ames Research Center.

and ducts, and chemically reacting flows in combustors. The ability to analyze three-dimensional chemically reacting flows in converging-diverging ducts for ramjets and scramjets was recently demonstrated by the Lewis Research Center. Significant progress had been made during 1989 in the development of high-temperature instrumentation technology. Silicon carbide semiconductor devices were demonstrated to retain diode characteristics up to 550 degrees Celsius.

Turboprop Flight Testing. During 1989 the Propfan Test Assessment aircraft was used to obtain a unique database for en route noise in cooperation with the Federal Aviation Administration. Ground-noise measurements, taken in conjunction with in-flight measurements during typical cruise operation, provide the basis for understanding source-noise propagation to ground level and its variation caused by atmospheric conditions. Propeller-blade-surface steady and unsteady pressure measurements were acquired to augment the fundamental coupling of aerodynamics and acoustics. During 1990 these data were analyzed to help develop and verify advanced multidisciplinary analytical noise prediction codes that include the aerodynamics, structures, and acoustics of rotating propeller blades for future design application.

Turbomachinery Multistage Flow Analysis. A multistage, average-passage turbomachinery analytical code was developed that provides the first adequate three-dimensional description of complex flow fields, including secondary vortices caused by viscous effects. Application of this code to four full compressor stages predicted the same flow choking phenomena seen in experiments but previously uncaptured by analytical techniques. Ongoing large, low-speed centrifugal turbomachinery experiments have provided the basic secondary flow and separation validation database for advanced three-dimensional codes that properly capture the complex flow physics.

Transport Propulsion Integration. Using Euler codes based on analytical capability developed in the Turboprop program, an advanced wing was designed to account for local interference of the propulsion pylon. This activity represented the first attempt to design an integrated wing-pylon-nacelle system and subsequent testing confirmed the absence of pylon interference.

Materials and Structures

Advancements in materials and structures technology enable introduction of new civil and military aeronautical vehicles with improved performance, durability, and economy. New materials and structural concepts are being investigated that withstand high aerothermal loading cycles in complex, lightweight airframe configurations.

In 1989 progress was achieved in development of enhanced diffusion bonding (EDB) for fabrication of titanium aluminide honeycomb-core sandwich panels. EDB has been shown to offer considerable potential for fabricating lightweight, high-temperature structures. Panels as light as 0.5 pounds per square foot have been successfully fabricated.

Research in superplastic forming has resulted in demonstration of compression panels with superplastic-formed aluminum stiffeners capable of sustaining loads 50 percent higher than the load capacity of panels having conventionally formed stiffeners. Material-research engineers have also established superplastic-forming parameters which permit unique shapes and configurations desired by the aircraft designer to achieve improved structural efficiency.

NASA has sponsored a program to develop low-cost fabrication processes for complex airframe structures. The geodesic-stiffened spar web developed as a result of this effort has proven to be a cost-effective and damage-tolerant airframe design approach. The objective of this effort was to achieve significant cost reductions in fabrication of composite structures by utilizing automated filament winding techniques, which reduce costs by 50 percent compared to conventional hand lay-up methods. Accomplishments to date include development of a method to filament wind composite spars in pairs using a one-step, fully automated process.

NASA's Advanced High-Temperature Engine Materials Technology program focuses on providing revolutionary composite materials and structures techniques for 21st-century transport engines. Emphasis is on polymeric-matrix composites, metal/intermetallic-matrix composites, and ceramic-matrix composites. Composites have been fabricated which maintain strength and toughness after thermal cycling from room temperature to 1,100 degrees Celsius for over 500 cycles without failure.

Research on supersonic flutter has been initiated using the Langley 16-foot Transonic Dynamics Tunnel at speeds to Mach 1.2. The wind-tunnel tests examined structural relationships between the supersonic-flutter problem and the weight of fuel carried in internal, wing fuel tanks. Researchers have developed capability to computationally predict unsteady transonic aerodynamic loads on realistic aircraft configurations. The new code can predict both the steady and unsteady pressure distributions over the entire aircraft surface. Shock-wave location and strength as well as aerodynamic interference between bodies can also be predicted. The capability has been verified by comparison with wind-tunnel data.

Information Sciences and Human Factors

New missions that stretch piloting capability and integrated systems that demand high-speed computational processing are the challenges confronting NASA's information sciences and human factors program. The technologies emerging from this rapidly expanding field of science provide the key to understanding, controlling, and optimizing a new family of aeronautical vehicles.

Controls and Guidance. Controls and guidance research is providing advanced technology to exploit concepts which dramatically improve the operational capabilities of civil and military aircraft. Major advances in aircraft control methodologies, reliability and validation techniques, and guidance and display concepts are taking place which greatly increase the efficiency and effectiveness of the next generation of fixed-wing aircraft and rotorcraft. The Advanced Transport Operating System B-737, used for in-flight applications of artificial intelligence to flight-control system software, has been returned to flight status following a modernization upgrade.

Human Factors. Human factors research endeavors to develop information display concepts that increase the pilot's understanding of an aircraft's performance while simultaneously reducing the pilot workload and error. NASA has developed an Engine Monitoring and Control System that allows the pilot to quickly assess the performance and status of the aircraft engines, crucial in high workload situations like takeoff and landing. Tests with a variety of pilots have indicated a high level of engine fault or abnormality detection that were missed about half of the time by the pilots using traditional displays.

The NASA rotorcraft, automated, nap-of-Earth (NOE), flight-research program is a cooperative activity with the U.S. Army, aimed at developing and demonstrating control, guidance, and sensing technologies for enhancing low-altitude/NOE flight. During 1989, pilots representing NASA, the Army, and the Air Force evaluated a computer-aided, low-altitude, flight-path guidance system for helicopters via simulation.

Computer Science. Fundamental studies of new architectures and algorithms for exploiting the full power of computers are being conducted at the Research Institute for Advanced Computer Science established at the Ames Research Center. The results will make significant contributions to computational fluid dynamics, computational chemistry, and other disciplines. The Sparse Distributed Memory project is investigating theory and applications of a massively parallel computing architecture that will support storage and retrieval of sensor and motor patterns required by autonomous systems.

Flight Systems

In each discipline area such as aerodynamics, structures, flight controls, and propulsion, there exists a need to validate research through actual flight testing of new components and systems. In some instances, aeronautical research can only be performed or validated in flight. This in-flight validation is frequently accomplished using high-performance aircraft as test platforms.

Heavy Rain. Heavy-rain effects on aerodynamic performance of aircraft in flight came under suspicion as a result of a DC-9 accident that occurred in heavy rain. NASA initiated small-scale, wind-tunnel tests to obtain a preliminary evaluation of heavy-rain effects. These tests showed a marked reduction (approximately 15 percent) in the maximum lift a wing can generate when it is operating in heavy rain (15 to 40 inches per hour). Though seemingly high, rain rates of these magnitudes have been measured for short durations of time.

The Aircraft Landing Dynamics Facility (ALDF) at the Langley Research Center was modified to incorporate an overhead sprinkling system capable of generating simulated heavy rainfalls. An airfoil was installed on the ALDF sled and a series of tests were performed to measure lift loss on a full-scale airfoil with a leading-edge slat and a double-slotted flap. The tests verified subscale data for the largest level of rainfall (that is, 40 inches per hour). Data from these tests will enable simulation of heavy rain effects on operational aircraft.

Icing Research. NASA has conducted a joint wind-tunnel investigation with Boeing on the effects of aircraft deicing fluids on aircraft aerodynamics. The investigation covered transport and commuter aircraft. It was determined that hold-over times critically affect fluid effectiveness. Typical hold-over times for fluids used in the United States average 5 minutes or less. While newer (thickened) deicing fluids increase this time by a factor of 4 to 6, these thickened fluids may not completely dissipate during takeoff roll for commuter aircraft, thereby causing aerodynamic penalties similar to those experienced by heavy rain.

Vortex Flap. Aerodynamic and performance flight tests of the vortex flap fitted to the NASA F-106B research aircraft has expanded the flight envelope to 4 g's. The wing/flap pressures, handling qualities, and the stability and control characteristics are being documented. Flight-test data are confirming and exceeding predicted performance improvements. A review of test results and flight experiment status have been presented to both the Boeing and the Douglas Aircraft companies.

High Angle-of-Attack Technology Program. This NASA program is a comprehensive aerodynamics, flight dynamics, and control research program that contains analytical, computational, wind-tunnel, and flight research elements. Emphasis is placed on the acquisition of detailed, flight-validated databases in high angle-of-attack environments (that is, to 70 degrees and beyond). A thrust vectoring control system has been installed that will enable extended pitch-and-yaw control on the test aircraft. The system is currently completing preflight tests and the first flight is scheduled for early October 1990. Vortex generators which will enable yaw control from the forebody of the aircraft are also being designed, developed, and tested. These devices will provide yawing moment forces by manipulating vortices shed from the forebody during high angle-of-attack flight.

A detailed database has been developed for the conventionally controlled F/A-18 aircraft. Data have been obtained enabling comparisons between predicted and flight-measured, aerodynamic flow characteristics. Advances in computational capabilities and in-flight flow visualization techniques have enabled comparisons of the flow characteristics within the boundary layer on the surface of the airplane, and in the vortices shed by the forebody.

Flight Research of F-15 Aircraft. NASA and the USAF successfully completed the first phase of the Self-Repairing Flight Control System (SRFCS) program. This program provided flight evaluation of a system designed to detect and isolate flight-control system failures, provide alert status to the pilot, provide onboard maintenance diagnostics, and assist in a reconfiguration strategy. Flight research for this program began in December 1989 at the NASA Ames-Dryden Flight Research Facility, in Edwards, CA, using the NASA F-15 Highly Integrated Digital Electronic Control (HIDEC) aircraft and was completed in June 1990. Flight research results confirm that SRFCS can detect and compensate for a simulated 80-percent loss of a horizontal stabilizer, for a fixed and locked stabilizer, and can perform maintenance diagnostics. SRFCS compensates for failures by movement of the remaining rudder, ailerons, and horizontal stabilizer surfaces to control pitch, roll, and airspeed.

The NASA Performance Seeking Control (PSC) program is also undergoing testing on the F-15 HIDEC aircraft. This program's objective is to increase overall aircraft thrust (defined as net propulsive force) and range performance by real-time-optimized control of the engine, nozzle, inlet, and horizontal stabilizers. A performance-seeking algorithm is designed to minimize fuel consumption during aircraft cruise; maximize excess thrust during climbs and dashes; and extend engine life by reducing fan turbine inlet temperature. PSC will optimize control of five engine variables, three aircraft inlet parameters, and the horizontal stabilizer position. Aircraft thrust increase in the subsonic flight envelope is predicted to range between 10 and 15 percent. Maximum power thrust in the supersonic flight regime is predicted to increase between 4 to 6 percent.

Systems Research and Technology

Systems technology programs carry new and innovative technology from the laboratory experiment into experimental and verification systems testing. These programs also provide for the design, fabrication, and testing of multidisciplinary aeronautical systems in order to greatly reduce technical risks associated with ultimate application.

Subsonic Transports

A major goal of the subsonic transport program is to establish technology that will enable the doubling of fuel efficiency of today's best subsonic transport aircraft, while substantially increasing productivity and affordability. Representative of efforts in drag reduction for subsonic aircraft is the cooperative program conducted with Boeing to obtain high-Reynolds-number data on advanced technology wings for computational fluid dynamics code development. Research efforts on the Takeoff Performance Monitoring System have completed full-task simulations with 41 experienced multi-engine pilots. The technology developed will enable a pilot to monitor not only the aircraft systems but the outside ambient environment as well. Payoff from this research is the potential reduction in takeoff-and-landing accident rates.

Rotorcraft

Rotorcraft research is focused on those barrier technologies which lead to development and validation for cost-effective design of highly efficient, low-noise-and-vibration rotorcraft. Overall program goals are to conduct systems studies to define configurations and technology requirements; focus research and technology efforts on high-performance rotorcraft; assess needed contributions from basic disciplines; and define a program of supporting technology for a high-speed rotorcraft. Recent emphasis in rotorcraft research has been focused on acquisition of an extensive rotor-airloads database, high-speed rotorcraft technology, and tiltrotor research in noise and performance enhancement. Joint programs with the DOD, the Federal Aviation Administration, and the U.S. helicopter industry result in constructive and closely coordinated national research efforts for rotorcraft technology.

Tiltrotor Technology. Tiltrotor research continued to support the U.S. Navy V-22 Osprey development by conducting a test of a 2/3-scale rotor in the 40-x-80-foot wind tunnel at Ames Research Center to measure rotor performance in forward flight. Testing also investigated download on the tiltrotor wing in hover. Measurements of the download were acquired for a wide range of rotor-thrust conditions and wing-flap angles. The effects of rotor rotation direction and rotor nacelle angle were also assessed. In cooperation with the Federal Aviation Administration (FAA), NASA is conducting a Tiltrotor Applications Study to investigate factors relating to an environmentally compatible and economically viable civil tiltrotor operating in the National Transportation System. The study is intended to identify areas of highest research payoff for best commercial vehicle configuration based on estimates of maximum market size. It is also intended to develop a better understanding of economic factors that influence successful commercial operation; identify changes for improved commercialization; conduct an operational analysis of design criteria and certification guidelines; and develop a comprehensive flight validation plan. NASA also conducted steep-approach simulations for the FAA that show promise for reducing noise and other siting restrictions.

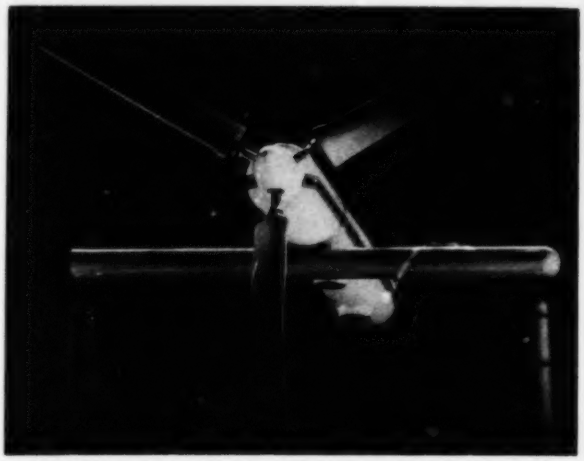
Advanced Rotorcraft Technology. A comprehensive rotor airloads program is under way to provide a database of airloads, blade dynamics, vibrations, and acoustics on a modern four-bladed helicopter. This cooperative effort with the U.S. Army conducts small- and large-scale wind-tunnel experiments and flight research with highly instrumented rotors. A UH-60 Blackhawk helicopter is being used in the flight research program. Pre-flight theoretical predictions using several rotorcraft analytical computer programs have been completed. The first phase of the flight investigation focused on rotor structural limits at high speed. In aeroacoustics, NASA is supporting innovative industry concepts for noise reduction. Validation of global-noise analysis was performed on two helicopters and the XV-15 and will continue on the UH-60 and the V-22 tiltrotor. Prediction methodologies for vibration analysis have been developed to assess rotor and fuselage structural dynamics. Mass tuning of the rotor and active vibration control techniques are being investigated to reduce vibratory loads. Active control is also being assessed for improved maneuverability through the use of rotor state control and individual blade control.

High-Performance Aircraft

NASA's high-performance aircraft research program is an integral and critical part of the overall aeronautics program. The program is structured to develop and mature technologies that have important military and civil applications. The technology programs are carefully selected to demonstrate significant improvement in performance or to show new capability that has high payoff.

Supermaneuverability. Achieving stable and controllable flight at extreme angles-of-attack approaching 90 degrees to the free stream airflow offers dramatic payoffs in military effectiveness. Collectively the technology is referred to as "supermaneuverability." Unprecedented high angle-of-attack capabilities utilizing propulsive control concepts were demonstrated with free-flying wind-tunnel models and simulation studies. Emphasis is placed on analysis and control of the flow in the high angle-of-attack environment (70 degrees and beyond).

X-29 Program Status. The X-29 program is a joint venture by NASA, the Air Force, and the Defense Advanced Research Projects Agency to investigate performance advantages and new options in configuration integration of forward-swept-wing, fighter-class aircraft. Concurrently, the opportunity was seized to test several other emerging technologies of high potential. These include relaxed static stability; three-surface longitudinal control; aeroelastic-tailored, composite, thin, supercritical wing; and digital flight-control systems.



V-22 Tiltrotor 2/3 Scale Rotor Performance Test in the Ames Research Center 40-x-80-foot Wind Tunnel.

The second X-29 aircraft, which is configured to expand the angle-of-attack envelope, first flew in May 1989. Functional-check flights and spin-chute-system flights were completed in July 1989. As of January 18, 1990, the second aircraft had completed 15 flights and cleared the 1-g flight envelope up to 43 degrees angle-of-attack. The aircraft has exhibited excellent roll-and-yaw characteristics, outperforming predictions. Currently, a military utility evaluation at high angle-of-attack is under way and is scheduled to be completed by the end of calendar year 1990.

Short Take-off and Vertical Landing Aircraft. The United States and the United Kingdom are nearing the end of a five-year program to develop advanced short take-off and vertical landing (STOVL) technologies aimed at reducing technological risk associated with the development of a next generation STOVL aircraft. One technology thrust was to develop airframe configurations that minimize hot-gas ingestion from the propulsion system recirculating back into the engine inlets, resulting in hover-performance degradation. An experimental activity was initiated at the Lewis Research Center's 9-x-15-foot, low-speed, wind tunnel to develop the analytical capability to predict when reingestion will occur and to provide for newly developed computational fluid dynamics codes.

Supersonic Cruise

U.S. trade with the Pacific community has increased dramatically, accelerating well beyond the volume of trade with Europe. Passenger aircraft that feature 350-passenger capacity, transpacific range, and cruise speeds in excess of two times the speed of sound will link the farthest reaches of the Pacific Rim area. A major technological challenge is the development of propulsion systems that will meet acceptable emission and noise standards and provide substantial reduction in fuel consumption while offering extended engine life at high, sustained operating temperatures. Other challenges include reducing airframe structural weight fractions, increasing cruise lift-to-drag ratio via supersonic laminar-flow control, and developing technologies to alleviate the impact of sonic boom for overland flight.

Boeing and McDonnell-Douglas have reported their findings from initial studies of market and technical viability of a high-speed civil transport. The studies identified barrier technologies arising from airport noise, sonic boom, and propulsion systems emissions that must be overcome in order to successfully implement a next-generation supersonic transport. NASA has subsequently defined a High-Speed Research program to address the barrier issues.

The engine emissions of primary concern are nitrogen oxides which, through a series of catalytic reactions, could have an adverse impact on Earth's protective ozone layer. Recent tests at the Lewis Research Center have demonstrated a six-fold reduction in nitrogen oxide production in a lean, premixed, prevaporized combustion rig.

Aircraft noise and its propagation in airport vicinities is a subject of significant concern. Technology development for supersonic transport noise reduction will combine both propulsion-system advances and the effect of improved lift-to-drag ratios on aircraft operation into an integrated role for reduction in overall noise levels near airports. Progress in cooperative efforts with industry include a 12-decibel reduction for mixer-ejector-type nozzles that retain the weight and performance characteristics required for operational systems.

Sonic boom is the result of a pressure disturbance caused by an aircraft flying at supersonic speeds. The goals for sonic-boom reduction research are to establish acceptability criteria for overland cruise; to develop predictive methodology for minimum boom concepts; and to verify prediction capability, particularly for atmospheric propagation. Analysis has shown that low-boom levels at high altitudes have significantly less "startle" effects on the ground.

Generic Hypersonics

The Generic Hypersonic program is an integrated, multi-disciplinary program aimed at continuing airbreathing hypersonic vehicle database development. The program focuses on key issues in hypersonics and emphasizes the establishment of hypersonic "know-how" independent of specific applications. The program stresses fundamental technical understanding of the controlling physical phenomena as well as innovation and provides capability to respond to both NASA and DOD future mission and application needs.

Ames Research Center has conducted investigations in aeroheating, control concepts, lightweight ceramic-matrix composites, and improvements to an arc-jet facility used to test and evaluate high-temperature insulation concepts. Langley efforts consisted of the development of three-dimensional, non-equilibrium, computational-fluid-dynamics flow field code; characterization of thin-gauge, metallic-substrate material formed by deposition; evaluation of high-L/D waverider configurations; investigations of the effects of contaminants on scramjet combustion; and analysis of actively cooled structural concepts. Lewis efforts focus on advanced high-speed propulsion inlet configurations, fundamental fuel/air mixing, and development of high-temperature reinforced composites.

NASA's expertise in hypersonic technology is being fully applied to the National Aero-Space Plane with the realization that its extremely broad range of technological needs challenges all disciplines. Future hypersonic vehicle concepts will be designed with the database developed from the multidisciplinary technology of the Generic Hypersonic program.

Wind-Tunnel Revitalization

In the conduct of aeronautical research and technology programs, NASA utilizes a unique complement of experimental wind-tunnel facilities. These facilities, valued at several billions of dollars, play a key role in supporting American industry in developing the Nation's civil and military aircraft. Unfortunately, many of these wind tunnels are now more than 30 years old.

A team of independent experts had conducted a critical assessment of the physical condition and productivity of the wind tunnels and projected demands for their use. The assessment indicated a serious need for modernization or refurbishment of many of the tunnels and their instrumentation, support equipment, and data systems. These findings were confirmed in separate reviews by NASA's Aeronautics Advisory Committee and the National Research Council's Aeronautics and Space Engineering Board.

NASA is in the process of carrying out a major 5-year, wind-tunnel revitalization program, scheduled to be completed in 1993. Current activity involves design work on three of the most urgent projects: replacement of the structural shell and refurbishment of the test section and equipment for the Ames Research Center's 12-foot pressure wind tunnel; rehabilitation of motors and critical equipment for the Lewis Research Center's 10-x-10-foot supersonic tunnel; and modernization of nozzles, heaters, and controls for the hypersonic facilities complex at the Langley Research Center. Construction on the Lewis tunnel and the Langley facilities began early in 1989.

National Aero-Space Plane

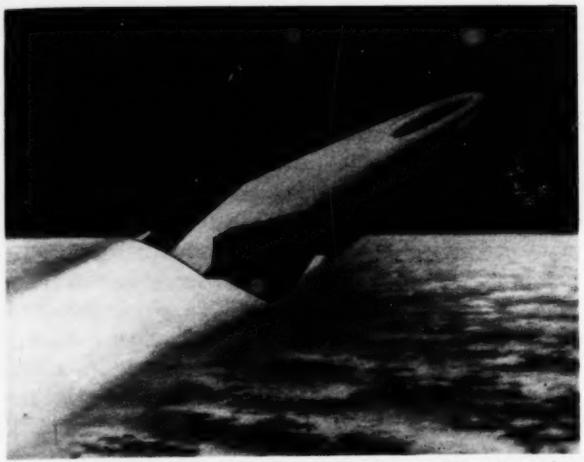
The National Aero-Space Plane (NASP) program was initiated in 1986 as a joint effort of NASA and the Department of Defense (DOD) to develop technologies for a new generation of aerospace vehicles for hypersonic cruise in the atmosphere or single-stage-to-orbit using airbreathing primary propulsion and horizontal takeoff and landing. NASP research and development is shared with NASA and DOD by a team of five major contractors. Pratt and Whitney and Rocketdyne are conducting work on propulsion; General Dynamics, McDonnell Douglas, and Rockwell are executing tasks related to the airframe and total vehicle integration. The program is defined to culminate with flight tests by an experimental vehicle, the X-30.

The National Space Council reviewed the NASP program in 1989. It reaffirmed the program objectives and recommended stretching the schedule by two and a half years to reduce technical risk. The decision to proceed with building and flight testing the X-30 is now projected to be made in the spring of 1993.

Wind-tunnel tests of scaled-model, X-30 configurations have significantly increased the experimental database from takeoff to hypersonic speeds. NASA's Numerical Aerodynamic Simulator has allowed analyses of highly complex flows through application of computational fluid dynamics. One example is the flow about a representative X-30 configuration at Mach 25 in which the air is chemically altered by the extreme heat of both friction and compression from shock waves.

Structures and materials technology continues to focus on high strength, light weight, and resistance to extreme heat loads. Material development has produced a substantial database on titanium aluminides, metal-matrix composites, and refractory composites. Theoretical chemistry and laboratory experiments are answering questions concerning compatibility of materials with hydrogen fuel. Structures work has demonstrated production techniques for fuselage panels and control surfaces developed from metal-matrix composites. Coated carbon-carbon specimens have survived combined mechanical and thermal loads simulating over 300 cycles of flight.

Propulsion research was highlighted by wind-tunnel tests at Mach 4 to 8 with scale models of four types of engines. Computational fluid dynamics and other analytical methods explored details of such phenomena as fuel/air mixing and combustion within the supersonic combustion ramjet at flight speeds above Mach 6. Work has included calculations at the molecular chemistry and physics level for combustion in ultra-hot, high-speed flows. Techniques for production and handling of slush hydrogen, kept at -423 degrees Fahrenheit, have been demonstrated. This denser fuel permits reductions in vehicle size and weight.



New design for the X-30 National Aero-Space Plane based on the best features of the individual designs of the five prime contractors.

Space Research and Technology

The primary goal of the Space Research and Technology program is to develop advanced technologies that enhance or enable our Nation's future space missions and, thereby, continue to ensure U.S. preeminence in space and space-related activities. To achieve this goal, a broad-based research activity program is conducted to advance the state-of-the-art in technology at the concept, subsystem, and system level; to develop technical strengths in the engineering disciplines within NASA, industry, and academia; and to perform critical flight experiments in areas where testing in the space environment is necessary for technology development.

Under the President's direction, the Nation will embark upon a bold new vision of space exploration for the 21st century. In this effort, NASA will develop the technology, capability, and infrastructure to monitor and study our own "spaceship" Earth, to return to the moon, and to go onward to Mars. In addition to manned exploration, a vigorous program to explore the solar system with robotic explorers will be pursued.

The Space Research and Technology program is structured into five technology thrusts related to Space Science, Space Transportation, Space Station, Exploration, and Breakthrough Technologies. To accomplish the technology for these thrusts, the Space Research and Technology program is composed of two complementary parts: the research and technology (R&T) base program and the focused technology programs.

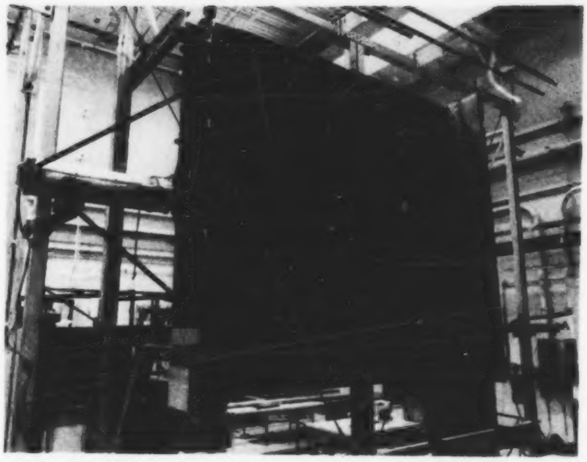
The R&T base serves as the seed bed for new technologies and capability enhancement. Through the R&T base program, usually at a sub-scale level, scientists and engineers develop forecasts regarding the potential applicability, usefulness, and overall benefit associated with new technologies. Once the potential applicability of a new capability is documented, decisions are made to carry selective discoveries into focused technology. A key element of the Space Research and Technology program is developing and sustaining a strong partnership with the university community. The goal of the R&T base University Space Research program is to enhance and broaden the capabilities of the Nation's engineering community through active research participation in the U.S. civil space program. The program is an integral part of the strategy to strengthen the space research and technology capabilities of the Nation.

Focused development is initiated based on the identified and projected needs of both current and future missions. Three focused programs have been initiated since 1988: the Civil Space Technology Initiative, the Exploration Technology (formerly called Pathfinder) program, and the In-Space Technology Experiments program. In the focused programs, technologies are developed for specific applications and products are delivered in the form of large-scale, hardware-technology demonstrations, software, and design techniques and methods.

This technology development is the vital first step in providing the capability to move out from Earth and expand our presence into the solar system. Significant progress was made in 1989 and 1990 in each of the principal thrusts and continuing efforts promise to show even greater results. Recent examples are described in the following sections.

Space Science Technology Thrust

NASA's Space Science and Applications program is divided into six major areas: Earth Science, Solar System Science, Astrophysics, Space Physics, Space Communications, and Microgravity. The Space Science Technology thrust supports technology efforts to expand capability



Advanced Photovoltaic Solar Array deployment tests.

and reduce costs through disciplinary advances, which increase science information return and spacecraft performance and enable the next generation of space science missions in these program areas. Missions such as the Earth Observing System will benefit from major technology advances in sensors, data storage, and onboard processors. Larger and inherently more flexible spacecraft will require that interactions between the control systems and the structure be better understood such that the total structure can be controlled to high levels of precision. Technology developments in advanced detectors can result in dramatic increases in Earth science data return because of increased detector sensitivity and resolution. Improvements in cooler technology can produce cost-effective results by extending mission duration and by increasing the effectiveness of detectors.

Advancements in thermoelectric materials, photovoltaic cells, and photovoltaic arrays could provide lighter weight, more efficient, nuclear- and solar-power sources for future planetary science missions and for solar electric propulsion systems for orbit transfer and interplanetary exploration. Technology development for in-space assembly and precision control of large multi-panel reflectors will enable large astrophysical telescopes to be assembled and used in space. The demonstration of submillimeter sensors and components will enable the study of galactic and stellar origins as well as atmospheric constituents.

Significant accomplishments were achieved in 1990 in several science-oriented technology programs. Advances were made in real-time data systems, propulsion, sensors and controls, and power systems. An example in real-time data systems is the Spacecraft Health Automated Reasoning Prototype (SHARP), an expert system designed to monitor the condition of interplanetary spacecraft and ground operations. SHARP demonstrated a significant leap in automation technology during the tough operational environment of Voyager mission operations during the encounter with the planet Neptune. The SHARP system automatically confirmed that a problem existed in attempting to recover and process data from the Voyager transmissions from Neptune. It then defined the magnitude and aided in the determination of the cause of the malfunction to a specific failed electronic unit on the ground which was replaced. Using traditional methods, this process of problem identification and isolation would have been both laborious and time-consuming.

In 1990, a submillimeter-wavelength, backward-wave oscillator (BWO) prototype was demonstrated. This enables the design of a high-frequency oscillator that is capable of significant power while being continuously tunable at submillimeter wavelengths. As a result, sensors can be developed in the use of very high-frequency submillimeter wavelengths for the space spectroscopy required for space astrophysics, upper atmosphere remote sensing, and solar system exploration.

The development of a high-efficiency, lightweight, rugged, radiation-resistant solar cell is an essential element of the NASA goals to achieve 300 watts per kilogram for a deployable planar array and 300 watts per square meter at 100 watts per kilogram in concentrator arrays. To achieve this development, researchers at NASA's Lewis Research Center are focusing on indium phosphide and gallium arsenide solar cells. Building upon last year's achievement of a record 22 percent efficiency in a prism-covered gallium arsenide cell operating in a simulated space solar intensity, Lewis researchers have developed a domed Fresnel lens which provides a working concentration ratio of 100:1. The use of this plastic lens means that it will be possible to build cheaper, lighter weight concentrator arrays for high-efficiency operation.

At the same time, NASA's Jet Propulsion Laboratory (JPL) has been working to develop an ultra-lightweight, high-performance, advanced, deployable, photovoltaic-array design that will be suitable for a broad range of long-term NASA space applications for the period beyond 1990. The goal of the effort is to achieve a specific power of 130 watts per kilogram, which is about six times higher than most arrays and twice as high as the high-performance experimental Solar Array Flight Experiment (SAFE) that NASA flew on the space shuttle in 1984. Analysis based on the components built and the detailed engineering drawings indicates that TRW, under contract to JPL, has achieved the 130-watts-per-kilogram goal.

Space Transportation Technology Thrust

The Space Transportation Technology thrust addresses the technologies that will provide safer and more efficient access to space while reducing the overall costs associated with space launch. Although, in some cases, these technologies will also provide additional capability for existing launch vehicles, these efforts are focused on providing the technology for the design of a new fleet of space vehicles, including new expendable and partially reusable cargo launch vehicles, fully reusable manned vehicles, and expendable and reusable space transfer vehicles. The thrust has been organized to address the pressing technology needs in the areas of Earth-to-orbit propulsion and transfer vehicle technology.

In order to significantly reduce the cost of access to space, transportation vehicles will have to be robust, operationally simple, and flexible. Technology advancements are required for more efficient vehicle structures, lightweight and more durable thermal protection materials, and lightweight and long-life cryogenic tankage. Approaches to lower manufacturing cost and improved productivity; autonomous systems; improved aerodynamic and aerothermodynamic prediction capability to increase vehicle margins; and adaptive guidance, navigation, and control systems for reduced sensitivity to changes in launch conditions are needed to reduce cost of both ground- and space-based operations.

Benefit studies indicate that significant weight and cost savings can be realized from a recent technology accomplishment in the materials and structures technology area. Panels of aluminum alloy were superplastically formed into stiffeners and spot-welded to aluminum skin structures. Tests of these structural components indicate their usefulness in the fabrication of cryogenic tanks for space transportation vehicles. Current research is focused on developing optimum cryotank structures through superplastic forming and resistance spot-welding of aluminum-lithium alloys. Weight reduction of 20 percent and cost reduction of 25 percent appear attainable.

Space propulsion technology accomplishments in 1989 and 1990 included the demonstration of a high-temperature, oxidation-resistant coating for uncooled bipropellant thrusters. The advanced thrust chambers increase life 10 times and specific impulse by at least 10 percent over existing thruster capability. This is made possible because the oxidation-resistant iridium coating enables the use of rhenium which is capable of operating at temperatures up to 4,000 degrees Fahrenheit, approximately twice that of conventional materials, but cannot withstand the effects of oxidation. The coatings are applied using a chemical vapor deposition technique. The program investigated the feasibility of extending the operating life of the shuttle's reaction-control-system vernier engines, by replacing the silicide-coated niobium chambers with those made of iridium-coated rhenium. The results of this investigation clearly showed that iridium/rhenium technology could eliminate or significantly reduce vernier chamber replacements.

As an element of a future onboard ascent-guidance system, the potential range of five different laser sensors was evaluated for use in lidar ("light detection and ranging" laser radar) wind sensors on launch vehicles. These laser sensors would provide data on the velocity of winds aloft and ahead of the vehicle. Using this information, adaptive guidance algorithms would compute structural-load alleviation trajectories for safe passage of the vehicle to orbit. This approach expands the wind velocity envelope into which a vehicle could be launched, providing operations savings and better on-time launch capability.

Also, during 1989 and 1990, a lifting-body design for an Assured Crew Return Vehicle for Space Station Freedom was analyzed. The lifting body, one of several options being studied, has the capability to provide large-entry cross-range, low-entry accelerations, and runway landing. The assessment of the lifting-body concept involved wind-tunnel studies and trajectory, performance, structural, and subsystems analyses. Additional research is continuing in entry and landing simulations and definition of structural concepts that offer ease of manufacture and access for maintenance.

One of the challenges of hypersonic flow-field simulation is the proper modeling of nonequilibrium processes within a computational fluid dynamics (CFD) code. A second challenge of hypersonic flow-field simulation, which is shared by simulations over all speed ranges, is the development of an algorithm which can effectively utilize the most advanced supercomputers to decrease the computational time required for a solution. The Aerothermodynamic Upwind Relaxation Algorithm, an advanced CFD code, has been developed to address these issues. This code, which provides numerical solutions to the governing equations for three-dimensional, viscous, hypersonic flows, has been implemented on a CRAY-2 computer. It can also effectively utilize both synchronous parallel and asynchronous parallel supercomputer architecture. The present capability represents the most comprehensive and generally available code for the study of thermochemical nonequilibrium effects in three-dimensional, continuum, hypersonic flows around advanced aerospace vehicles such as the aeroassisted space transfer vehicle.

Space Station Technology Thrust

The Space Station Technology thrust addresses the technologies that will increase safety and human productivity on the initial space station, enhance its productivity and efficiency as a laboratory and testbed for science and technology, and enable future growth.

Automation and robotics are areas receiving specific emphasis. Several technologies, such as the development of artificial intelligence applications to enable systems autonomy for routine operations and fault detection and telerobotics to reduce the astronaut EVA time for maintenance and payload operations, are being pursued. Significant accomplishments include the laboratory demonstration of the first dual-arm telerobotic manipulator. The arms have seven degrees of manipulative freedom and can be used both in the teleoperator and robotic mode to perform external maintenance tasks. An additional important achievement during the past year was the development of a high-fidelity graphics phantom robot that uses the latest graphics display techniques to simulate the dual-arm robotic action in response to teleoperator commands and thus enable the precise planning of the telerobotic tasks.

The data collected on space environmental effects from the Long Duration Exposure Facility (LDEF) are playing a significant role in the space station design. The LDEF, which was retrieved by the shuttle in January 1990 after five and a half years in low-Earth orbit, carried 57 technology experiments contributed by NASA centers, other Federal laboratories, U.S. industries, and universities, as well as space agencies and universities of foreign countries. Over 10,000 specimens of construction, thermal protection, and solar-cell materials are now being evaluated for their resistance to the corrosive effects of atomic oxygen and radiation. Because of the extended time the spacecraft spent in space, it is also providing extremely valuable data on the number and size of meteoroid and space-debris impacts. The LDEF data will enable the characterization of the environment that the space station will encounter during its planned 30-year lifetime and aid in decisionmaking on the choice of materials for construction, debris shielding, and other important factors.

A new space construction technique recently developed by the Langley Research Center and demonstrated in the Neutral Buoyancy Facility at the Marshall Space Flight Center could enable astronauts to construct large structures such as the space station truss seven times faster than the fully manual method presently planned. This technique utilizes an astronaut mobility platform on either side of a general-purpose mobile transporter. The platforms are suspended from the transporter by arms that allow the astronauts fully controlled planar motion (back-forth, up-down) along the truss bay. The transporter holds magazines that automatically dispense each truss element as needed. After constructing a section, the transporter would crawl along the recently constructed structure and become a platform for the construction of a new segment.

In preparation for increasing the power capability of the space station via solar dynamic power, a new material for thermal energy storage has been identified and tested. Germanium metal has high thermal-storage capacity on melting and lacks the disadvantage of the low thermal conductivity in the solid state that the salts (which are presently the thermal-storage materials of choice) exhibit. The major drawback of germanium, its highly corrosive action on common container materials, has been over-

Exploration Technology program's multi-chassis, six-wheeled planetary rover being tested in rugged terrain at the Jet Propulsion Laboratory.

come by using graphite. Germanium specimens in graphite capsules have been cycled 600 times at the appropriate temperatures without measurable corrosion on the container. New design techniques and materials could enable the construction of lightweight concentrators, heat receivers, and thermal energy storage for the solar dynamic modules now under development for Space Station Freedom.

Exploration Technology Thrust

The objective of the Exploration Technology thrust is to develop the critical technologies required for future solar system exploration missions including establishment of a base on the moon and manned exploration of the planet Mars. This effort will develop a broad set of technologies that will enable new and innovative capabilities, increase reliability and reduce risk for human missions beyond low-Earth orbit, reduce development and operations costs for long-term exploration efforts, and enhance performance for human and robotic missions.

The Exploration Technology program, which was started in the fall of 1988 as the Pathfinder program, supports the President's National Space Policy directing that we begin to plan for future solar system exploration missions. On July 20, 1989, President Bush challenged the Nation to set forth with a renewed commitment to exploration:

"First, for the coming decade, for the 1990's, Space Station *Freedom,* our critical next step in all our space endeavors. And next, for the new century, back to the Moon. Back to the future. And this time, back to stay. And then a journey into tomorrow, a journey to another planet: a manned mission to Mars."

The Exploration Technology program is a critical step supporting that Presidential directive by establishing a foundation of technology for these future missions of exploration. The Exploration Technology program, as a partnership between NASA, industry, and academia, will enhance our Nation's "cutting edge" in the highly competitive arena of aerospace technology. The Exploration Technology program is developing new technologies in several broad areas to enable future robotic and piloted solar system exploration: surface exploration, in-space operations, human support, space transportation, lunar and Mars science, information systems and automation, and nuclear propulsion.

During 1989 and 1990, the first 2 years of the Exploration Technology program, progress was made in a number of key areas. The Exploration Technology program supports NASA's contribution to the ongoing U.S. space nuclear power research and development program, the SP-100 program. The SP-100 program, which is a joint NASA, Department of Defense, and Department of Energy endeavor, successfully completed key accelerated life testing of reactor fuel pin elements. With no appreciable swelling of the fuel pins even after 5 percent fuel burn-up, the testing demonstrated that lifetimes of 7 years should be achievable with SP-100 technology, a critical step toward bringing this important technology to maturity for application at a lunar outpost early in the next century.

Also in 1990, preliminary technology development in the sensors areas of the Sample Acquisition, Analysis, and Preservation program was made. In particular, a spectrometer breadboard for visible and near-infrared sensing was completed and demonstrated, which could be applied to sensor systems for early robotic Mars sampling missions. Also, testing was conducted on rock-coring techniques and parameters using a research robotics arm and drill fixture in a laboratory environment. In addition, in 1990, the Exploration Technology Program Planetary Rover effort completed fabrication and began testing of two experimental mobile robot concepts: a multi-chassis, six-wheeled rover concept and a six-legged walking rover concept. Both rovers traveled over benign and rugged terrain as part of this testing phase. These experimental robots will form the foundation for continuing development of mobile robotics software and navigation technologies which will support future exploration of challenging—but scientifically intriguing—areas of both the moon and Mars.

In the area of human support in space, an innovative exercise facility was completed at the NASA Ames Research Center which will be used to study the human metabolic response to orbital extravehicular activity (EVA) work. The facility incorporates a controlled atmosphere chamber, an EVA work exercise device which duplicates upper body movements in zero-gravity conditions, human metabolic instrumentation to monitor blood pressure, body temperature, respiration rates, carbon dioxide and water expiration, and oxygen intake. Human metabolic responses to simulated EVA work will be obtained so that thermo-regulatory control methods may be designed to more accurately reflect the EVA work requirements resulting in increased astronaut comfort within a space suit, particularly for increased EVA missions approaching 8 hours.

In space transportation, the first successful operation of a compact, high-speed, liquid-oxygen turbopump with a gaseous oxygen drive was achieved. This type of turbine, pumping liquid but driven by gas, is crucial to the development of a future high-performance expander cycle engine critical to deep-space exploration. In addition, a major contracted effort was initiated to fabricate an advanced engine testbed which will enable integrated component testing.

Breakthrough Technologies Thrust

Within the Space Research and Technology program, the purpose of the activities supported by the Breakthrough Technologies thrust is to advance high payoff, highly innovative technology concepts that could provide revolutionary advances in the approach to future space missions and programs. These efforts, which are often referred to as a technology "push" as compared to a requirements-driven "pull," stimulate and nurture innovative and creative ideas and support fundamental research in space technology at the NASA centers and national laboratories, in universities, and with industry.

Breakthrough technologies may produce a significant jump in the performance level of a space system above the extrapolated performance that would result from just the normal, expected growth in the technology state-of-the-art. They may provide new instruments, tools, and techniques that permit solutions to problems that have been previously conceived as not solvable. Breakthroughs may also allow space operations to occur in performance regimes that were previously technically impossible.

As an illustration, breakthrough technologies in advanced propulsion concepts range from high energy/density propellants, advanced fission/fusion, remotely energized (beamed) propulsion, and anti-matter. Advanced power concepts include fuel cells using in-situ materials as reactants and laser-power beaming which involves beaming power from a solar-collecting satellite to a planetary surface. Advanced materials include long-duration space lubricants and advanced composites.

During 1989 and 1990, two breakthrough activities reached fruition and provided excellent examples of revolutionary advances in space technology. One activity was the demonstration of a computer program called AUTOCLASS which uses artificial intelligence techniques to automatically classify data. The benefit of AUTOCLASS is that it can provide for the automatic discovery of patterns in very large data sets. Dramatic results were achieved in the analysis of results from the Infrared Astronomy Satellite (IRAS) through the automatic discovery of several unexpected patterns of data, which are now being investigated. Many applications for this technology are being examined, including pattern discovery in weather and medical data.

A second example is the Sparse Distributed Memory program which was successfully completed with shape, speech, and text translators demonstrated. This associative memory with massively parallel architecture provides an extremely large address space and enables information to be structured, filtered, and linked to other stored information in the process of storing data. Based on an effort to understand human long-term memory, it is capable of abstraction and generalization and provides the basis for future autonomous systems that can learn from experience. This could provide artificial intelligent

The VLSI (Very Large Scale Integrated) chip developed for operational use as part of the Hubble Space Telescope ground data system by the University of Idaho Center for Space Engineering Research, shown here on a penny to indicate scale.

behavior capability for tasks too remote, too hostile, or too tedious for humans.

University Space Research

Nine university centers, selected in 1988 to participate in the University Space Engineering Research Center program, completed their first year and have already shown significant technical and educational benefits. For example, the Mars Mission Research Center at North Carolina State University and North Carolina A&T University are pursuing a joint research activity with the McDonnell Douglas Company for an in-space Mars aerobrake assembly. They will fabricate a mock aerobrake structure and assemble this structure in a neutral-buoyancy tank. The University of Idaho Center for Space Engineering Research for Very Large Scale Integrated (VLSI) System Design is developing a compression/decompression VLSI chip for operational use as part of the Hubble Space Telescope ground data system.

This program has begun to offer valuable educational benefits as well as attracting more graduate and undergraduate students to pursue aerospace careers, supporting new graduate level classes and introducing new material into undergraduate courses, and supporting cross-discipline and department thesis topics. This effort is an important contribution to broadening the Nation's engineering capability to meet the critical needs of the civil space program.

Human Exploration of the Moon and Mars

During 1989 and 1990 the Office of Exploration (now the Space Exploration Directorate in the Office of Aeronautics, Exploration, and Technology) continued to lay the foundation for human exploration of the moon and Mars. Previous years of study provided a basis for President Bush's historic announcement on July 20, 1989 of the Space Exploration Initiative, a long-term commitment to expand human presence beyond the confines of Earth. The initiative's goals include the establishment of a lunar outpost early in the 21st century and human arrival on Mars by 2019. A near-term plan was developed in 1990 for acquiring the knowledge and capabilities this Nation needs to pursue its exploration goals. The plan will be modified based on results from the outreach and synthesis process, an activity developed by NASA and the National Space Council to search the Nation for new and innovative ideas and technologies on how best to accomplish the Space Exploration Initiative.

1989 Case Studies

During the first several months of 1989, the Office of Exploration continued the analysis begun in 1988 of three exploration case studies: 1) Lunar Evolution; 2) Mars Evolution; and 3) Mars Expedition. These studies, which follow up four case studies conducted in 1988, were framed to provide information on the requirements for human exploration of the moon and Mars. The studies evaluated requirements in such areas as Earth-to-orbit transportation, planetary transfer, and planetary surface operations. The Lunar Evolution case study examined ways to gradually consolidate a permanent lunar outpost where we could perform life sciences research as well as take advantage of unique scientific opportunities in astronomy, geology, physics, and other fields and where human beings could learn to become self-sufficient away from Earth. Similarly, the Mars Evolution case emphasized a flexible and gradual outpost buildup employing advanced technologies. The Mars Expedition case emphasized a quick, visible, non-permanent effort to realize the first human exploration of Mars using current technologies and knowledge. Together with the 1988 case studies, these studies provided NASA with preliminary conceptions of key mission requirements.

Announcement of the Space Exploration Initiative

On July 20, 1989, the 20th anniversary of the Apollo 11 moon landing, President Bush articulated a vision for the U.S. future in space including the establishment of the space station, a lunar base, and a manned mission to Mars. This vision, known as the Space Exploration Initiative, sets the course for the Nation to fulfill the National Space Policy goal of "expanding human presence beyond Earth orbit into the solar system."

90-Day Study

In response to the President's announcement of a long-term commitment to human space exploration, the NASA Administrator created a task force to conduct a study to validate that the Nation could accomplish the goals laid out by the President. The "Report of the 90-Day Study on Human Exploration of the Moon and Mars," the task force's product, drew from much of NASA's exploration work conducted over the past several years. By examining five reference approaches to human exploration of the moon and Mars, the report provides reference material on potential requirements in technology and other areas, as well as an examination of the scientific opportunities and other potential benefits. The report contains no specific recommendations, but does point out some prerequisite activities for any human exploration program:

- exploration technologies;
- robotic missions;
- heavy-lift launch vehicle;
- Space Station Freedom;
- life sciences research.

After completing the 90-Day Study, NASA continued studying various mission architectures and developed a near-term plan consistent with the needs identified in these studies and the direction contained in subsequent Presidential policy directions.

Presidential Policy Directions

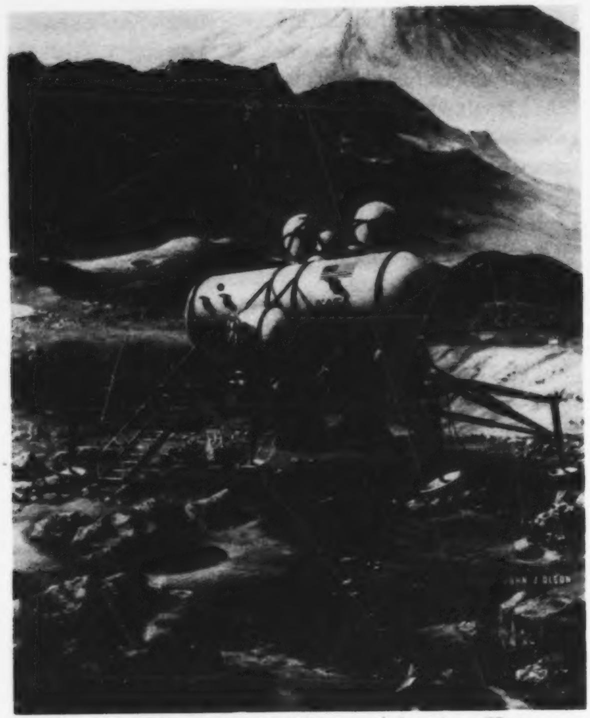
On February 16, 1990, President Bush approved the following policy for the Space Exploration Initiative:

- The initiative will include both lunar and Mars program elements;
- It will include robotic science missions as well as human missions;
- The near-term focus will be on technology development, with an emphasis on new or innovative approaches and technology with the potential to make a major impact on cost, schedule, and/or performance;
- Mission, concept, and system analysis studies will be conducted in parallel with technology development;
- Selection of a baseline program architecture will occur after several years of defining two or more reference architectures while developing and demonstrating broad technologies; and
- NASA will be the principal implementing agency, while the Department of Defense and the Department of Energy also will have major roles in technology development and concept definition.

On May 11, 1990, the President provided a specific goal for the first human landing on Mars. He said "I believe that before Apollo celebrates the 50th anniversary of its landing on the moon—the American flag should be planted on Mars."

Outreach and Synthesis

In accordance with Presidential policy, and at the request of Vice President Quayle, in the summer of 1990 NASA began a nationwide outreach effort to search for new and innovative concepts and technologies for the Space Exploration Initiative "to ensure that all reasonable space exploration alternatives have been evaluated" prior to embarking on this ambitious effort. Developed by NASA in coordination with the National Space Council,



Artist's rendition of an expeditionary outpost on Mars.

the outreach program solicited inputs in three major ways: 1) a direct solicitation from universities, industry, research associations, and the general public, evaluated by the RAND Corporation; 2) an assessment by the American Institute of Aeronautics and Astronautics of ideas from the aerospace community; and 3) inputs from other Government agencies and national laboratories. These inputs and others are being evaluated by a high-level Synthesis Group composed of individuals from NASA, other Government agencies, industry, and academia. By early 1991 this group will provide a report to the NASA Administrator which will include several mission architecture options, technology priorities, and possible early milestones for the Space Exploration Initiative. The NASA Administrator will report to Vice President Quayle and the National Space Council. Results of the outreach and synthesis process will be the basis for mission studies and technology development to be conducted over the next several years, leading to a Presidential decision on a specific architecture. NASA will modify its near-term plan where needed to respond to the Synthesis Group's recommendations.

Science Studies

Together with the Office of Space Science and Applications, the Office of Exploration conducted a number of science workshops and studies in 1989 and 1990 to understand more clearly the scientific opportunities presented by a program of human exploration and how best to take advantage of those opportunities. Both robotic science missions and human interactive science will be conducted as part of the Space Exploration Initiative and the opportunities cover a number of scientific disciplines: solar physics, geology, biology, astrophysics, chemistry, and space physics. A number of fundamental science themes for the Initiative were identified in the 90-Day Study:

- How were Earth and the moon born and what was their shared early history?
- Did life ever start on Mars?
- What is the relationship between the sun, planetary atmospheres, and climate?
- Are there worlds around other stars?
- What is the fate of the universe?

An Exploration Science Working Group was established in 1990 to refine science goals for the moon and Mars and to oversee planning for science in the Space Exploration Initiative.

International Cooperation

When he announced the Space Exploration Initiative, President Bush asked Vice President Quayle and the National Space Council to determine, among other things, the feasibility of international cooperation. The National Space Council concluded that "international cooperation in this endeavor is feasible and could offer significant benefits to the United States, subject to the satisfaction of national security, foreign policy, scientific, and economic interests."

On March 30, 1990, the White House announced that the United States would seek an exploratory dialogue with other nations on international cooperation in the Space Exploration Initiative. The dialogue will focus on conceptual possibilities for cooperation with Europe, Canada, Japan, the Soviet Union, and other nations as

Artist's depiction of an observatory on the far side of the moon.

appropriate. Guidelines for the dialogue were prepared by the National Space Council. The initial discussions are tentatively scheduled for 1991.

Interagency Coordination

The Space Exploration Initiative involves several Government agencies. To facilitate coordination, NASA signed a Memorandum of Understanding with the Department of Energy in June 1990. An agreement with the Department of Defense is under discussion. In addition, NASA invited other agencies, including the Departments of Commerce, Education, the Interior, and Transportation, the National Institutes of Health, and the National Science Foundation to provide ideas through the outreach and synthesis process.

Near-Term Plan

A near-term plan for fiscal years 1992-1996 was developed to respond to the Space Exploration Initiative strategy as defined in the President's policy directive. The plan will be modified to incorporate the Synthesis Group's findings. Key activities of the plan now include:

- Perform mission and system implementation studies of synthesis architectures;
- Initiate critical technology development to enable promising implementation options;
- Initiate other enabling research activities; and
- Begin critical long-lead development programs.

Department of Defense

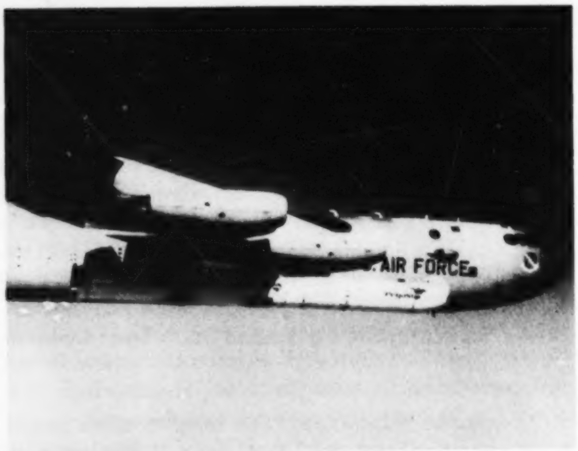
Space Activities

Space Launch. NASA's shuttle launched four DOD programs continuing a recovery program that began with the successful mission of Discovery in September 1988 and the flight of Atlantis in December 1988. The remaining DOD shuttle flights are scheduled to end in 1992; consequently, DOD's on-orbit capability will increasingly be provided by Air Force expendable launch vehicles.

The first Titan IV was successfully launched in June 1989. By 1996, Titan IV production enhancements and dual pads on each coast could provide a launch capacity of up to 10 per year. Five Delta IIs, carrying Navstar Global Positioning System (GPS) satellites, were launched in 1989, in addition to three commercial Delta I launches. In FY 1990, eight Delta boosters were launched carrying three GPS, one Strategic Defense Initiative Organization, one NASA, and three commercial payloads. The Atlas II launch system, which is being developed to meet the needs of the Defense Satellite Communication System beginning in 1991, continued in development. The Titan II is operational for launch of Defense Meteorological Satellites, as well as other payloads, into unique polar orbits. In addition, the Air Force will provide near-term expendable launch vehicle launches on a cost-reimbursement basis to support NASA's mixed fleet launch requirements.

The Defense Advanced Research Projects Agency initiated a program in FY 1989 to conduct the initial test launches of the Pegasus Air-Launched Space Booster. The Pegasus booster is a three-stage, solid-propellant, inertially guided winged launch vehicle. It is carried aloft by a conventional transport or bomber-class aircraft to an altitude of about 40,000 feet where ignition of its first stage motor is initiated. Pegasus currently has the capability of placing a 500-pound spacecraft into a 250-nautical mile circular polar orbit. The first launch of Pegasus occurred on April 5, 1990, successfully carrying a three-function payload (PEGSAT) into orbit. A second Pegasus launch is planned for the spring of 1991.

In the near term, increasing requirements for on-orbit satellite services will exceed DOD's launch capability. This projection points to requirements for higher reliability, lower cost, assured access to space. To meet these future requirements, the Air Force continued concept definition started in 1988 to address a new mixed fleet of launch vehicles. As a first step in this process, initial concept definition studies were completed for an Advanced Launch Development program. This effort is addressing methods to significantly reduce launch costs, improve operational responsiveness, and meet future demands for assured access to space. NASA and DOD are partners in this effort. System design will continue in support of the pacesetter development of a 580,000-pound thrust engine that could lead to a family of versatile, responsive launch vehicles for the next century.



Pegasus Air-Launched Space Booster being carried to altitude by a B-52 aircraft for launch on April 5, 1990.

The Navy has also been addressing the problems of launch cost and responsiveness with a concept called SEALAR, for Sea Launch and Recovery. SEALAR is a modern version of an 1960s concept which used simple pressure-fed rocket motors to launch a floating rocket directly from the sea. By allowing the lower stages to fall back into the sea without elaborate recovery methods, these simple devices offer potential for reuse. Additional potential benefits are the use of environmentally safe liquid fuels and the flexibility to select the launch-site latitude for maximum efficiency. Although the effort continues in the research stage, drop tests, above- and below-water test firings of the rocket motors, and full-duration/full-thrust static tests of the suborbital vehicle have been successfully conducted.

Commercial Launch Activities. The Department of Defense continues to support the fledgling American commercial space launch industry in a number of ways.

The Air Force space launch centers at Patrick and Vandenberg Air Force Bases have supported commercial programs with Government-supplied services, facilities, and expertise provided on a direct-cost basis. Commercial space launch services have been selected for the Navy's Ultra High Frequency (UHF) follow-on program. The Navy has entered into a Memorandum of Agreement (MOA) with Space Science Incorporated of America to conduct four sounding rocket flights at the Naval Ordnance Test Station, White Sands, NM. Through 1989, one successful launch under a previous MOA and one successful launch under the current MOA have been accomplished.

Satellite Systems. Satellite on-orbit mission capability improved, and data distribution to military users grew in volume and quality in 1989 and 1990. This measure of merit for responsive DOD space operations has become increasingly relevant as research and development efforts in satellite survivability, mobile ground processing centers, and secure information distribution are integrated into the operational inventory. Following is the status of the various Defense satellite programs.

Communications

Fleet Satellite Communication System. The Fleet Satellite Communication System (FLTSATCOM) FLTSAT 8 satellite, the last of a series of Navy UHF communications satellites, was successfully launched in September 1989. The second FLTSAT Extremely High Frequency package to be used for testing Milstar terminals was aboard. Authorization has been received to acquire the full 10 satellite UHF Follow-on constellation which will replace the FLTSATCOM program. In addition, an Extremely High Frequency (EHF) package has been authorized for satellites 4 through 9. Hughes Aircraft Corporation, builder of the system, has signed a contract with General Dynamics for commercial launch services to place the 10-satellite constellation into orbit beginning in 1992.

Air Force Satellite Communications/Single-Channel Transponder. The Air Force Satellite Communications (AFSATCOM) is a satellite communications capability providing reliable global communications among the National Command Authorities and the nuclear-capable forces via FLTSATCOM, the Defense Satellite Communication System/Single Channel Transponder (DSCS/SCT), and other host satellites. The primary missions support dissemination of emergency action and force-directing messages to deployed forces, including associated report-back communications. The system terminal segment consists of fixed and transportable ground terminals as well as airborne terminals via a transponder control system. During 1990, the Single Channel Transponder (SCT) on the DSCS III entered the service. These measures will provide more survivable Super High Frequency (SHF) service for strategic users. The Milstar system will begin to replace these missions with assured EHF communications in the early 1990s.

Defense Satellite Communications System. The Defense Satellite Communications System (DSCS) is the long-haul, high-capacity communications system supporting worldwide command and control of our forces. In addition, DSCS supports the transfer of wide-band data and users of the Diplomatic Telecommunications System. The space segment of DSCS is planned for five operational satellites and two on-orbit reserves. The current space segment consists of three DSCS IIIs and two DSCS IIs, as well as two limited-capability DSCS IIs and one DSCS III reserve. The launch of a DSCS III and a DSCS II satellite in 1989 helped alleviate the marginal status of the constellation. When the 10 DSCS III satellites now in production or storage are launched, we will be capable of supporting the critical user community through 2000. Concept work continues for a DSCS III follow-on upgrade program, and on the development of a common, interoperable, anti-jam SHF modem for DSCS terminals.

The DSCS control segment provides real-time monitoring and control for optimum use of resources, thereby maximizing user support. Efforts continued to consolidate all DSCS operations centers under the Army Space Command. Contracts are also in place to move toward a contingency control capability during 1991 through 1994.

The ground segment consists of a family of large, medium, and small Earth terminals with associated communications equipment supporting both the strategic and tactical user communities. All 39 new AN/GSC-52 fixed terminals have been accepted for activation through 1991. With these activations, the total terminal population using the DSCS exceeds 500. In addition, actions were continued to define the next-generation Earth terminal needed to support the expanded requirements of the late 1990s, and to plan for replacing or upgrading the aging terminals currently within the networks.

Milstar. Milstar is a multichannel, Extremely High Frequency/Ultra High Frequency (EHF/UHF) satellite communications system that will provide survivable, enduring, jam-resistent, and secure voice/data communications for the President, the Secretary of Defense, and the Commanders in Chief of the Unified and Specified Commands, tactical and strategic forces, and other users. It will be used for the worldwide command and control of U.S. strategic and tactical forces during all levels of conflict. Milstar satellites will be launched into high- and low-inclination orbits to provide full Earth coverage. The first satellite is now entering a period of intensive ground testing prior to an early 1990s launch. Fabrication of the second and third satellites also continues. The Air Force is the lead service for the procurement of Milstar satellites, the dispersed mission control network, and the airborne terminals. The Army and Navy also have terminal development and procurement programs.

The Milstar multi-Service terminal segment operational test and evaluation has been successfully completed through Phase III of interoperability testing. Testing on the Navy's terminals was completed in September 1990. The results validated the frequency-hopping waveform and other terminal technical characteristics, as well as demonstrating operations in some field environments. In a proof-of-concept testing, the three Service terminals communicated among each other via a Milstar emulator orbiting on a FLTSATCOM satellite. Each Service terminal also completed Phase I testing with a breadboard version of the Milstar satellite payload. The field tests of land, sea, and airborne terminals included a destroyer, a submarine, and a transport aircraft. A plan identified the minimum number of communications nets, satellites, and terminals to provide an Initial Operational Capability. Low-rate initial procurement contracts for Air Force terminals was awarded in CY 1989, and in FY 1990 for the Navy terminals. The first terminals are well into fabrication.

Satellite Laser Communications. In 1989, a joint technology demonstration effort between the Navy and the Defense Advanced Research Projects Agency (DARPA) was conducted to provide the capability to communicate via the Satellite Laser Communication system from a spacecraft to a submerged submarine using a laser beam as the transmitting medium.

LightSats. DARPA launched its first generation LightSats aboard a Scout booster on May 9, 1990. The two 150-pound UHF-band communications satellites, known as MACSATs, provide store-and-forward message relay (analogous to electronic mail between connected user terminals) in support of tactical operations and other defense missions. The spacecraft can additionally operate with unattended remote sensors to recover stored data, and to relay commands from a central control facility. DARPA's LightSat initiative will continue to develop the key enabling technologies to improve the performance and capabilities of future "microspace" defense satellites, as well as to enhance the cost-effectiveness of major large satellite systems.

Navigation

Navstar Global Positioning System. The Navstar Global Positioning System (GPS) is a space-based navigation system to satisfy requirements for worldwide, accurate, common-grid, three-dimensional positioning/navigation, and precise time transfer for military aircraft, ships, and ground personnel. The system is composed of three segments: user equipment, satellites, and the control network.

In 1989, approximately 4,000 DOD receiver terminals were on order or in use. The first five operational GPS (Block IIR) satellites were launched during the year on new Delta boosters. The control segment updates the satellite broadcasts which provide positional accuracies for military users to within 16 meters and for civil users to 100 meters.

Initial deliveries of user equipment to all three Services began in 1989. Installations are well along on many different ships and aircraft. The current mix of developmental and operational satellites provides worldwide, two-dimensional coverage at least 15 hours a day; the completed constellation of 21 satellites will provide full-time, three-dimensional navigational information.

Meteorology

Defense Meteorological Satellite Program. In 1989, the two-satellite Defense Meteorological Satellite Program (DMSP) constellation provided timely, high-quality, worldwide visible and infrared cloud imagery, and other specialized meteorological, oceanographic, and solar geophysical data to support DOD strategic missions. DMSP also provided real-time direct readout of local weather to ground- and ship-based tactical terminals supporting DOD forces worldwide. This was particularly important during "Operation Just Cause" in Panama. DMSP weather data provided real-time support to the on-scene Commander and gave advance warning of aircraft icing conditions at key continental U.S. staging bases. As a result, preventive measures were implemented and missions proceeded on schedule.

Surveillance and Warning

Defense Support Program. An upgraded Defense Support Program (DSP) satellite (DSP-1) was launched in 1989 on the first Titan-IV space launch vehicle. DSP-1 will provide DOD with enhanced missile warning and surveillance capabilities and will include a second-color focal plane and mission data message broadcast. The program's endurability/survivability is provided by its mobile ground processing system, geosynchronous orbit, and satellite characteristics. Air Force planning is now under way for a DSP follow-on system, the Advanced Warning System.

Space Control

Kinetic Energy Anti-Satellite Weapon System. The Kinetic Energy Anti-Satellite Weapon System (KE ASAT) Program is an effort to develop a near-term, surface-launched weapon system capable of non-explosive neutralization of satellites. The KE ASAT program is part of a national ASAT capability to include surveillance sensors, Battle Management/Command, Control, and Communications elements, and both Kinetic and, ultimately, Directed Energy Weapons.

The KE ASAT Joint Program Office (JPO) was established on February 27, 1989, within the U.S. Army Strategic Defense Command, Huntsville, AL, with the Army as interim lead Service of the joint-Service effort.

Since then, the JPO performed a Cost and Operational Effectiveness Analysis Study establishing the national security need and military utility of a U.S. ASAT capability; validated program costs before the DOD Cost Analysis Improvement Group; and selected a best technical approach for a missile design.

Based upon a Defense Acquisition Board recommendation, the Under Secretary of Defense for Acquisition selected a land-based system to meet the U.S. Commander in Chief of the Space Command's highest priority near-term ASAT mission needs and retained the Army as the lead Service for the KE joint program office. The Air Force retains responsibility for ASAT battle management and command, control, and communications, as well as overall system integration.

Strategic Defense Initiative. The Strategic Defense Initiative (SDI) program is in its seventh full year of research to determine the feasibility of effective defenses against ballistic missiles, and it continues to make excellent progress across a broad range of technologies. During 1989 and 1990 we conducted a record number of major experiments and tests crucial to program success.

To intercept a missile or reentry vehicles, defenses first must detect (see, discriminate, and identify), acquire, and track the targets under a variety of conditions. SDI continues to operate a broad-based program to collect target signatures. This data collection program includes numerous sounding rockets to put up sensors to view targets and decoys against different Earth and space backgrounds. It also includes various airborne, shipborne, and ground-based sensors to collect signature data. The airborne platforms include an NC-135A equipped with sensors that operate in the visible- through long-wavelength infrared bands and a Learjet equipped with ultraviolet- through medium-wavelength infrared sensors. In addition, SDI has an aggressive program to explore and develop multiple technologies to discriminate decoys from reentry vehicles by passive, active, and interactive means. This program is supported by activities which build and test various decoys to see what will stress a strategic defense system.

Specific 1989 and 1990 accomplishments include the Janus flight experiment in which a high-resolution infrared imager was used to collect target signatures of post-boost vehicles. The Delta Star satellite detected and tracked numerous launches and provided extensive data on rocket plume signatures. The Airborne Surveillance Testbed, a modified 767 to be used to validate airborne long wavelength infrared (LWIR) surveillance sensor functional performance and to provide a test bed for advanced surveillance technology, started flight tests. The technology advancements to be tested include LWIR sensor components, real-time onboard signal and data processing, target signature measurements, and aero-optic effects and controls. The Excede III experiment was launched with two payload modules. An electron beam module excited the upper atmosphere while a sensor module measured atmospheric response emissions in the ultraviolet through the infrared wavebands. Data will be used to validate predictions of the effects of nuclear detonations on the upper atmosphere. Other experiments were launched to collect ultraviolet data on the rocket plumes of solid- and liquid-fueled rockets and on the bow shock of an ascending rocket. Ultraviolet background data were also obtained. After attacking missiles or reentry vehicles are detected, they would be engaged and destroyed by interceptors. A series of space-based interceptor hover tests demonstrated the ability to track rocket plumes and handover to the missile hardbody. Even more importantly, this series of tests demonstrated SDI's miniaturization of electronics, propulsion systems, and navigation systems, and development of high-strength, lightweight structures. The first integrated technology flight experiment from the ground-based High-Endoatmospheric Defense Interceptor demonstrated the ability to effectively cool the forebody and sensor window of an interceptor intended to intercept a reentry vehicle in the atmosphere during the terminal phase of a ballistic missile's flight. This demonstration showed that the sensors would not be disabled by heat from atmospheric friction. The Brilliant Pebbles space-based interceptor technology experiment series was initiated. The initial flight, first of a series of 12 experiments scheduled over the next three years, successfully exercised the launch operations, launch vehicle, and experimental set-up. Launch vehicle motors performed adequately. However, the launch vehicle did not successfully deploy the probe. Hence, specific Brilliant Pebbles propulsion and sensor systems were not tested. The test data are being reviewed to determine the source of the problem and to identify corrective action. In addition, several Brilliant Pebbles key components, such as sensor, navigation, and communication systems have been tested "piggyback" fashion aboard the Delta Star space experiment.

Much progress has also been made in ensuring that strategic defenses can be integrated and managed, always with man-in-the-loop control. The National Test Bed is being established to develop, test, and validate strategic defense concepts and software. High-fidelity end-to-end simulations are being built that allow defense concepts to be tested against a variety of realistic threat models. This effort provides a basis for the development of command and control concepts and permits early-user involvement. An early version of a command center was successfully demonstrated at the Army Advanced Research Center. This demonstration showed that, with man-in-the-loop, there is sufficient time to assess, react to, and engage attacking missiles throughout the battlespace. A system software program has been established to address the large-scale integration of software for a defense system. During 1990 the National Test Facility hosted three command-and-control games bringing the total to five. Game 90-1 involved players from U.S. Space Command and Strategic Air Command. It was built on a space-based interceptor architecture and modeled interface with strategic offensive forces. Game 90-A was an early Brilliant Pebbles architecture. The final game of the year provided an initial Brilliant Pebbles capability. Throughout the year games were tailored to specific command-and-control objectives based on lessons learned, new user requirements, changes in strategic defense architecture, and increased simulation fidelity.

Ensuring that a strategic defense system will be survivable was furthered as a result of underground nuclear tests conducted to validate the survivability of systems components such as electronics, optics, and structures in a nuclear environment. Red/Blue team analyses also were conducted to examine the ways in which an attacker might try to defeat the defenses and to establish effective measures to offset those attempts. Results were fed back into the efforts to design both the systems and their operational concepts.

Significant progress in advanced technologies, such as directed energy, has also been made. The key issues being examined are target acquisition, pointing and tracking, and beam lethality. During a 1989 ground test, the Alpha chemical laser demonstrated the capability to produce a high-power beam. This milestone in the space-based laser program was a vital step in scaling such devices to power levels required for strategic defense. The Beam Experiment Aboard Rockets was the first test of a neutral particle beam in space. The experiment employed a relatively lightweight power supply that can be packaged for space operation. The test demonstrated that complex directed energy weapons could be reliably operated in space. In 1990, the two long-term directed energy space experiments were launched from Cape Canaveral: the 2 1/2-year Low Power Atmospheric distortion effects on laser beams; and the 1-year Relay Mirror Experiment that will demonstrate the relay element of a ground-based laser. The two experiments were launched together aboard a commercial Delta II launch vehicle. Also aboard the LACE (low-power atmospheric compensation experiment) satellite is an experiment package to gather neutron background data to support development of neutral particle beams for interactive discrimination.

Tremendous technical progress has been made in areas such as reduced manufacturing costs and lightweight structures. SDI is supporting various means to manufacture large-scale staring and scanning infrared detector arrays. Research in detector materials, fabrication, and testing has reduced the cost of imaging sensors from hundreds of dollars per picture element (pixel) to a few dollars per pixel. The SDI also supports programs to fabricate lightweight, high-strength space structures from advanced composite materials. These and other advances are being used to reduce costs and enhance the performance of prospective components of the Strategic Defense System.

Also worthy of note is the wealth of spin-off applications of SDI technology development to other Department of Defense missions, Government agencies, and the commercial sector. SDI technology may have other defense uses such as reducing the weight and cost of air-to-air missiles. The space station and the National Aero-Space Plane should benefit from SDI advances in computing, signal processing, and lightweight structures. Optical technologies development could lead to a new generation of very high-speed, low-cost supercomputers. Neutral-particle-beam technology may have applications in areas such as airport bomb detection, cancer therapy, and non-destructive inspection of manufactured items such as rocket-motor components. SDI research is creating commercial opportunities in superconductivity, diamond crystal coatings, communications, industrial manufacturing processes, electronics, and microwave technology.

Hardened Space Electronics Program. The Defense Nuclear Agency's (DNA) radiation-hardened electronics program has successfully demonstrated the design, fabrication, and technology transfer of very-large-scale integrated (VLSI) circuits. During 1990, significant progress in this advanced VLSI technology was made by the demonstration of a 256-kilo-bit static random access memory (SRAM) fabricated on advanced silicon-on-insulator material. These SRAM devices, used in all space-based computer systems, are immune to the degrading effects of trapped high-energy charged particles and random erroneous computer states caused by cosmic rays. The use of hardened electronics eliminates the need to remove power from space systems as they pass through the radiation belts.

In addition, hardened power integrated circuits are considered essential components in advanced space systems. During 1990, high-power integrated circuits were demonstrated that are immune to circuit burnout and gate rupture from high-energy particles and cosmic rays. Hard fiber-optic links to these power circuits were also evaluated.

Progress has also been made in the transfer of immune-electronics technology to space systems through the joint DNA/NASA hardness assurance working group. The development of radiation test facilities, uniform test methods, and radiation test standards has increased the application of advanced electronics in space systems during 1989 and 1990. For example, hardened electronic circuits have been used in space systems such as Galileo, GPS, DMSP, and Mars Probe.

Aeronautical Activities

Advanced Technology Tactical Transport. Flight testing of a 62-percent scale Advanced Technology Tactical Transport (AT^3) proof-of-concept (POC) demonstrator aircraft was completed by the Defense Advanced Research Projects Agency (DARPA) in July 1989. An impressive volume of actual flight-test data were obtained on a unique tandem-wing design with both long-range and significant short-takeoff-and-landing (STOL) capabilities. After the highly successful completion of the flight-test program, the POC airplane was delivered to the Air Force flight test museum at Edwards Air Force Base.

The demonstrator was designed, built, modified, and tested by Scaled Composites, Inc., of Mojave, CA, under an innovative fixed-price contract with specific payment milestones and no Government acceptance specifications. The contractor retained responsibility for all construction, flight testing, configuration control, and safety, with minimal Government intervention.

After an initial series of tests ended in November 1988, the aircraft was extensively modified by cutting off the entire cruciform tail section and adding tail booms as extensions of the two engine nacelles. The resulting twin-tail configuration greatly improved the directional stability and engine-out minimum control speed and enhanced the cargo loading characteristics. Design performance goals for a full-scale AT^3 include an unrefueled range of 2,400 nautical miles, with a midpoint landing-and-takeoff roll of 1,000 feet with a 12,000-pound payload. Flight testing indicated that performance very close to this is achievable.

The AT^3 POC established a different approach to the development of a new aircraft configuration by replacing conventional wind-tunnel testing with a subscale flight article. The POC aircraft enabled configuration development normally accomplished with a wind-tunnel model, while simultaneously obtaining test data in flight environments not possible in wind tunnels.

The objectives of the overall DARPA AT^3 program were to identify alternative prototyping and acquisition approaches and to document the AT^3 as one example of a prototype program.

Pilot's Associate Program. The Pilot's Associate program is applying many of the technologies being developed under the DARPA Strategic Computing Program to the problem of real-time, combat-pilot decision aiding. The Pilot's Associate is being designed as a knowledge-based system to be embedded in future avionics systems, both for new production and for retrofit to existing aircraft. The specific technologies being developed and applied include artificial intelligence, automated planning, advanced man-machine interface, and the supporting computer technology necessary for their implementation. The program seeks to demonstrate the technological feasibility of airborne mission replanning and execution in response to either command redirection or drastic differences between the expected and the encountered situation. A mature Pilot's Associate will provide the pilot of a single-seat fighter aircraft with expert assistance in the highly dynamic and demanding environment of aerial warfare. The Pilot's Associate will support tactical decisions and system management in an integrated environment of computer-aided situational awareness. The program includes increasingly challenging demonstrations in advanced flight simulators representative of the fighter aircraft of the mid-1990s.

In early 1989, the Pilot's Associate program demonstrated a distributed, artificially intelligent mission replanning system which performed route planning and threat-avoidance planning during a simulated air-to-ground attack mission. This system performed in real time on a network of computer workstations which drive an advanced panoramic cockpit display in a full-mission flight simulator.

In late 1989, the Pilot's Associate program demonstrated a relatively robust system which performed complex intercept-and-maneuver planning during a simulated strike escort mission. This system showed the complexity of defending a flight of strike aircraft from enemy attack by coordinating the actions of four escort aircraft against a concerted attack by four enemy interceptors. The interface to the pilot was controlled by an artificially intelligent system which modeled pilot behavior in order to determine pilot display requirements and compensate for pilot errors and inattention. The distributed system was implemented on a network of advanced laboratory processors which formed the link between the flight-simulation facility and an experimental cockpit. The system dramatically demonstrated intercept planning, route replanning, observable signature management, threat avoidance, attack planning, sensor management, display management, and aircraft system management at levels of performance which were considered beyond the capability of the unaided pilot. Future demonstrations planned for late FY 1991 and early FY 1992, will demonstrate real-time, man-in-the-loop capability with an ultimate demonstration of the application of ADA software to real-time artificial intelligence software.

The program is now identifying the best match between the possible computer hardware architectures and the software requirements which have been derived thus far. Application studies are currently ongoing for both the F-16 and F/A-18, and a future application committee made up of industry and service leaders has been formed to provide guidance for further application of this technology. Every effort is being made to ensure that future Pilot's Associate systems will be compatible with the emerging aircraft avionics standards for hardware and software

National Aero-Space Plane. The National Aero-Space Plane (NASP) is a joint Department of Defense (Air Force, Navy, Defense Advanced Research Projects Agency, and Strategic Defense Initiative Organization) and National Aeronautics and Space Administration program. The objective is to develop and demonstrate the enabling technologies for an entirely new generation of hypersonic flight vehicles including space launch vehicles capable of single-stage-to-orbit with horizontal takeoff and landing, and hypersonic aircraft capable of long-range hypersonic cruise within the atmosphere. The requisite technologies can be integrated into the design and fabrication of an experimental research aircraft, the X-30, for flight test and demonstration. These demonstrated technologies could then provide the basis for follow-on military and civil vehicles capable of: global unrefueled operation, reaching any point on Earth in less than two hours; providing routine "on demand" access to space; reducing payload-to-orbit costs by at least an order of magnitude; and flexibly based, rapid response space launch. Such NASP-derived aerospace systems would provide a revolutionary increase in civil and military capability.

While the X-30 design is not yet firm, some characteristics can be specified. The X-30 is envisioned to be a manned aerospacecraft powered by ramjet/scramjet engines that will be fueled by liquid or slush hydrogen. It will have auxiliary rocket engines for final orbit insertion and on-orbit maneuvering. The vehicle structure will be manufactured from advanced, high strength, lightweight, heat-resistant materials and critical portions of the structure will be actively cooled with the super-cold hydrogen fuel before it is burned in the engine.

The NASP program is making solid progress. The airframe and engine designs meet the program goals, and component hardware fabrication and ground tests are producing impressive results. Among recent accomplishments of the program are the following:

- Major structural demonstration components including cryogenic tankage and wing/fuselage attachment structures were fabricated.
- X-30 designs which meet program goals were refined based on extensive test and computational data.
- Scale-up of durable, high-temperature materials (such as titanium aluminides, titanium metal matrix composites, oxidation-resistent coated carbon-carbon) was begun.
- Computational-fluid-dynamics codes were updated and validated with wind-tunnel data. Effects of chemical reactions have been included in the codes.
- Tests on leading edges, nose caps, and actively cooled surfaces were successfully completed.
- Mach-8 engine test facilities were checked out and high-speed, ramjet/scramjet engines (component and subscale engines) were tested.

During the current technology development phase of the program the NASP contractors are contributing over $700 million of their own resources to the program.

B-1B. Several Air Force and DOD reviews highlighted the fact that the B-1B has, for the most part, achieved its baseline requirements. Progress has been made in solving the defensive system shortfalls. In July 1989, the ALQ-161A "Core" contract was awarded and established an achievable baseline for the defensive system which will provide effective countermeasures against the most critical threats to the B-1B. In September 1990, on schedule, the Air Force began the critical laboratory testing of this "core" system. When combined with the B-1B's low-altitude, high-speed ingress capability, these defensive measures will result in excellent penetration capability for the aircraft.

The B-1B's ability as a bombing platform was superbly demonstrated in the Strategic Air Command's 1989 bombing and navigation competition (Bomb Comp). The B-1B placed first and third in the overall competition, winning the coveted Fairchild trophy. A B-1B unit was awarded the Crumm trophy for the best bomber unit. For the second year in a row, B-1B units swept the Dougherty static random access memory (SRAM) competition, winning first, second, and third places. In a 1989 Operational Readiness Inspection, a B-1B aircraft and crew scored the best bomb scores in the Strategic Air Command's history.

B-2 Advanced Technology Bomber. Flight testing of the B-2 began on July 17, 1989, with a 1-hour-and-53-minute flight from Palmdale, CA, to Edwards AFB, CA. The B-2 design is an highly aerodynamic, efficient, flying wing which produces a high-payload and long-range capability and employs low observable or stealth technology. Northrop is the prime contractor with Boeing, LTV, and General Electric Aircraft Engine Group being some of the major subcontractors. The unique capabilities of the B-2 will allow it to fly through enemy airspace virtually unchallenged by air defense weapons now and well into the 21st century.

Since July 17, 1989, the B-2 has flown 16 flights for a total of 67.1 hours with no major problems. Flight testing will continue in late October 1990, following completion of a planned stand-down period. The B-2 has undergone extensive testing prior to its first flight including over 24,000 hours of wind-tunnel tests, over 44,000 hours of avionics test and evaluation, and 6,000 hours of flight-control test and evaluation. There are 16 aircraft in various stages of manufacture, with six in the final assembly stage. The B-2 test aircraft, to include the first vehicle, are manufactured using production processes, greatly simplifying the transition to production.

The program buy was adjusted from 132 to 75 aircraft as a result of a DOD major aircraft review completed in April 1990.

C-17. The Air Force's C-17 is a new design, intercontinental range, air refuelable, airlift aircraft capable of routine operations onto 3,000-foot runways and austere airfields, and airland/airdrop delivery of outsize cargo. The program is now in its fifth year of full-scale development, and second year of production of test aircraft, under contract with Douglas Aircraft Company. Low-rate initial production approval was granted on January 18, 1989. Concerns over schedule slippage and cost escalation resulted in a number of management actions during 1989. In July 1989, Douglas Aircraft Company selected General Electric Control Systems as the new electronic flight controls system subcontractor. Douglas also signed an agreement with DELCO, the mission computer subcontractor, making Douglas responsible for mission computer software management. DELCO continues to perform software development/integration with Douglas as the overall manager.

Advanced Fighter Technology Integration. The Advanced Fighter Technology Integration (AFTI/F-16) program continues evaluation of advanced technology integration in support of the Close Air Support/Battlefield Air Interdiction mission. This Air Force/Balanced Technology Initiative program culminated in a joint tactical experiment with the Army at Fort Hood, TX, in December 1989. Equipped with a laser spot tracker, the AFTI/F-16 acquired a target designated by an Army field unit, digitally transmitted the target information to a second F-16, and acquired another target. The F-16s then performed a coordinated two-ship attack. All this was done *without* voice communication. The test demonstrated increased acquisition range, improved identification of targets, and two-ship first pass attack. The AFTI/F-16 will next demonstrate a night-attack capability using head-steered forward-looking infrared sensors, helmet-mounted sight integrated with night-vision goggles, and automatic digital terrain-driven terrain following.

X-29 Advanced Technology Demonstrator. This unique aircraft has demonstrated the viability of forward-swept, aero-elastically tailored composite wings, successful digital control of a 35-percent statically unstable aircraft, and excellent stability and longitudinal control derived from coupled canards. Flight testing is continuing at NASA's Dryden Flight Research Facility at Edwards AFB, CA, where the X-29 number two aircraft is evaluating agility at high angles of attack. This testing will assess tactics, explore envelope fringes, and identify aircraft performance limitations. The aircraft has been flown at 30 degrees angle of attack and will be tested to maximum controllable angle of attack, probably around 70 degrees. So far, the aircraft has flown better than wind-tunnel predictions.

A-12 Avenger. During the 1989-1990 period, the A-12 Avenger was under development by the Navy to replace the 30-year old A-6E Intruder for the long range, day/night all-weather strike mission. Its design incorporates low-observable technology, greater speed and advanced weapon and survivability systems to enable it to penetrate sophisticated defenses and deliver greater quantities of ordnance—with greater precision and at less risk to the flight crew—than any previous naval aircraft. The A-12 would provide the carrier battle group commander greater mission flexibility with its ability to covertly penetrate deep into enemy territory, without having to be refueled, to strike targets well beyond the reach of current sea-based strike aircraft. Its automated electronic cockpit would provide the crew with a variety of systems to aid in detection and avoidance of enemy air defense threats. The A-12's low-observable materials and composite construction were designed to withstand the corrosive rigors of the carrier environment and its greatly improved reliability and maintainability would mean higher aircraft readiness rates with lower life-cycle support costs.

At the end of FY 1990, the A-12 program was in its 32nd month of full-scale development. The contract for the first lot of six production aircraft in the total buy of 620 A-12s had been executed.

F-14D Super Tomcat Fighter. The F-14D Super Tomcat Fighter will complete Operational Evaluation in November 1990. It provides significant technological improvements over the F-14A which has been in service for the Navy since 1973. Using the proven airframe design of the F-14A, the F-14D incorporates the 30-percent more powerful F110-GE-400 General Electric engine, and the new Hughes digital APG-71 radar to provide better targeting for the Phoenix (AIM-54C) missile, and a digital data bus which links two new computers with the improved avionics suite and all weapons. The capability to carry and accurately deliver air-to-ground weapons is currently being tested and should reach the fleet in mid-1991.

F-15 Short Takeoff and Landing/Maneuver Technology Demonstrator. The Air Force's F-15 Short Takeoff and Landing/Maneuver Technology Demonstrator (STOL/MTD) is a highly modified F-15B design with enhanced maneuver capability and STOL performance. Aircraft modifications include: pitch-axis thrust-vectoring/thrust-reversing engine exhaust nozzles, full-authority canards, integrated flight and propulsion controls, and rough-field landing gear. The result is an aircraft with additional control in the pitch axis and improved up-and-away maneuver and deceleration performance. It is designed to take off and land on a 50-x-1,500-foot icy runway during 30-knot crosswinds with no external, ground-based landing aids. The first flight with all modifications (including the two-dimensional nozzles) was conducted on May 10, 1989. The integrated flight and propulsion control system, using the vectoring capability of the nozzles, is yielding improved performance. The rough-field landing gear has been tested by taxiing over a simulated bomb-damaged runway, and night landings have been accomplished using only onboard radar and infrared sensors.

F/A-18C and F/A-18D Night Attack Aircraft. The F/A 18C (single seat) and the F/A 18D (dual seat) Night Attack aircraft began delivery to Navy and Marine Corps squadrons in October 1989. New sensors and displays in these aircraft allow aircrews to fly low-altitude night strikes with the same accuracy and situational awareness as is possible during daylight. The new components consist of a navigation forward-looking infrared pod, night-vision goggles, a raster heads-up display, special cockpit lighting compatible with the night-vision goggles, a digital color moving map, and independent front and aft seat multipurpose color displays.

Advanced Tactical Fighter. The Advanced Tactical Fighter (ATF) program is developing the next-generation Air Force fighter to counter the Soviet threat projected for the late 1990s and beyond. As a follow-on to the F-15, the ATF is being designed to penetrate high-threat enemy airspace and support the air-land-sea battle forces with "first-look, first-kill" capability against a technologically advanced, numerically superior enemy. The ATF's improved capabilities will be made possible by significant technological advances in the areas of signature reduction, aerodynamic design, flight controls, materials, propulsion, sensors, and integrated avionics. It will reach operational capability in the next decade.

In April 1986, the ATF program was restructured to include flying prototypes and ground-based avionics prototypes in the demonstration/validation phase of the program. The restructured program implements Packard Commission recommendations; emphasizes "fly-before-you-buy" and competitive contracting; and provides the means to reduce technical and cost risks before entering full-scale development.

The Defense major aircraft review delayed the start of ATF production from FY 1994 to FY 1996; reduced peak production from 72 aircraft per year to 59 aircraft per year; and delayed peak production from 1999 to 2002. These results reflect fiscal constraints and a delay in the anticipated threat. The ATF program remains carefully structured to reduce technical risk and cost, while maintaining qualitative air superiority enjoyed by the United States since World War II.

Light Helicopter. The Light Helicopter (LH) program is developing the next-generation Army aerial scout/attack helicopter to counter worldwide threats in the late 1990s and beyond. The LH exploits advances in propulsion, materials, electronics, and sensor technologies to provide day and night target-acquisition capability and a helicopter capable of operating in high-altitude and hot-temperature environments with a full design payload, a capability not now widely available to the Army. The LH will reach operational capability in the late 1990s and will replace the AH-1 Cobra attack helicopters and the OH-58A/C aerial scout helicopter, both of which have been in the inventory since the 1960s and are becoming tactically obsolescent.

Concept exploration for LH began in 1983. Initial program goal was to replace the old scout/attack helicopters (AH1 and OH-58A/C) as well as the old utility helicopters (UH-1). Because of affordability, the LH program was restructured in 1988 and focused on replacing only the scout/attack portion of the fleet. In 1990, taking advantage of the reduced threat posed by the Warsaw Pact, the system deployment was slowed by two years to add a prototype demonstration phase before proceeding into full-scale development. Full-scale development for the fuel efficient T-800 engine began in 1985 and the engine is currently undergoing final qualification tests. Full-scale development for the entire LH system is planned to start in late 1994.

X-31A Enhanced Fighter Maneuverability. The X-31A Enhanced Fighter Maneuverability program is a joint DARPA/Navy effort with the West Germans to develop an experimental aircraft to explore and understand the technical requirements and tactical advantage of supermaneuverability. Aircraft number one rolled out in the spring of 1990, at Rockwell International's Palmdale, CA, facility. Aircraft number two is nearing completion. A novel, low-cost prototyping technique, that substantially reduced tooling costs, proved to be extremely successful in keeping costs low while conforming to a very ambitious schedule. Development and validation of the X-31A flight software continues as a joint effort between U.S. and German technical and pilot teams through the coming year as a parallel effort with ongoing taxi testing and the following flight-envelope expansion of the aircraft. Upon completion of a series of medium- and high-speed taxi tests, successful testing of all aircraft systems, and subsequent flight certification by the Navy, the aircraft is expected to make its first flight.

Department of Commerce

Space Systems

Satellite Systems

The Department of Commerce's (DOC) has four components involved with space activities. One of these, the National Oceanic and Atmospheric Administration (NOAA), through its National Environmental Satellite, Data, and Information Service (NESDIS), continued to operate its polar-orbiting and geostationary spacecraft for remote sensing of Earth's environment, collection and relay of data from in situ observing platforms, search and rescue, and sensing of the space environment. In full operation, the polar-orbiting system consisted of two NOAA spacecraft, one each in sun-synchronous morning and afternoon orbits at a nominal height of 850 kilometers. The geostationary system, called GOES for Geostationary Operational Environmental Satellite, lost the older of its two satellites, GOES-West, in January 1989. The remaining GOES spacecraft was subsequently moved to a more centralized geographic position and continues to function normally.

Instruments carried by the polar-orbiting spacecraft included an Advanced Very High Resolution Radiometer (AVHRR) to obtain visible and infrared imagery; a Television-and-Infrared-Operational-Satellite Operational Vertical Sounder (TOVS) for profiling atmospheric temperature and moisture from Earth's surface to the top of the atmosphere; an Earth Radiation Budget Experiment (ERBE); a Solar Background Ultra-Violet (SBUV) sensor for measuring ozone distribution and concentration; a Space Environment Monitor for observing near-Earth, charged-particle spectra; a Canada/France-provided Search-and-Rescue package to detect and locate emergency distress signals; and a France-provided Data Collection System (DCS) to collect, relay, and pinpoint observations sensed by moving and stationary platforms such as buoys, balloons, and wildlife.

The instrument complement on the GOES satellite included a Visible-and-Infrared-Spin-Scan-Radiometer Atmospheric Sounder (VAS) for visible and infrared imaging and sounding; a Space Environment Monitor; a Search-and-Rescue package; and a DCS to collect and relay observations from fixed stations such as river gauges, tide gauges, and anchored and drifting buoys. The communications systems onboard the GOES were also used to broadcast a weather facsimile (WEFAX) service, consisting of satellite pictures, weather charts, and other environmental information to properly equipped ground stations in the Western Hemisphere.

NOAA Series. The NOAA-9, NOAA-10, and NOAA-11 satellites provided the polar-orbiting service. NOAA-10 and NOAA-11 are the primary operational satellites providing a full complement of data. NOAA-9 operates in a standby mode, providing limited ERBE and SBUV data.

The next polar satellite, NOAA-D, is scheduled for launch in 1991. The satellite completed its spacecraft qualifications tests in December 1989.

The next generation of polar satellites, NOAA-K/M, completed the Critical Design Review in August 1989. This new generation of polar satellites will carry improved instrumentation for all weather atmospheric soundings.

GOES Series. GOES-East provided double duty, making up for the loss of GOES-West, by being positioned at 108 degrees West longitude for observing winter storms in the Pacific and at 98 degrees West longitude for observing Atlantic hurricanes during the summer months. NOAA will continue this operation until the launch of GOES-I, expected in 1992. The GOES-West satellite stopped transmitting images in January 1989. After generating more than 1,300,000 pictures, the satellite's imaging system (VAS or the Visible-and-Infrared-Spin-Scan-Radiometer Atmospheric Sounder) failed. The spacecraft was launched on April 28, 1983, with a design life expectancy of five years. NOAA engineers extended its life to almost six years by careful management of its instruments. This made GOES-West the longest-lived GOES spacecraft in the series.

The Ford Aerospace and Communications Corporation continued the development and fabrication of the next-generation GOES spacecraft, GOES-I/M, and associated ground equipment. The GOES-I prototype imager instrument began its initial system integration testing in December 1989. GOES-I is scheduled to be launched in mid-1992.

Planning for a new generation of geostationary weather satellites, to follow GOES-I/M, began in January 1989. A GOES requirements workshop was conducted by NOAA to collect information from the current users of geostationary satellite data. In August 1989, NASA started

Example of the global vegetation index data produced at the EROS Data Center. Depicted are the annual normalized difference days for 1987. This black-and-white photograph was produced from the original false-color composited photograph.

a Phase-A study to assess technology feasibility, science requirements, and the cost of this next proposed series of geostationary satellites.

The new DCS completed its first full year of service in 1990. The new system increased the number of remote data collection platforms which NOAA can support from 8,000 to 100,000 and provides a real-time broadcast of all data collected by the system. Rather than installing a costly GOES receiving system or using telephone lines for accessing data, users may install low- cost Ku band receivers and connect them to personal computers to receive and process data. Utilizing only one imaging satellite, the DCS has continued its international coverage (Eastern Atlantic to Western Pacific) using transponders from other non-imaging GOES.

Landsat Series. Pursuant to the Land Remote-Sensing Commercialization Act of 1984, the Earth Observation Satellite Company (EOSAT) operated both the Landsat 4 and 5 remote-sensing satellite systems for NOAA in 1989. During this time, these systems acquired 37,000 images for domestic use, while providing 320,000 images to foreign ground stations. In 1990 345,000 images were acquired by foreign ground stations and 25,000 images for domestic use; domestic images decreased because of the aging spacecraft.

The National Space Council undertook a policy review of the Landsat program during 1989. The Council recommended and the President approved a policy of ensuring continuity of Landsat-type data. EOSAT continues to manage the design and development of Landsat 6 which is scheduled to be launched in 1991.

In 1989, 15 foreign ground stations received Landsat data. Pakistan became officially operational in 1989, and EOSAT negotiations with the Government of Ecuador for a ground receiving station were also concluded.

Search-and-Rescue Satellite-Aided Tracking. During 1989 and 1990, the international search-and-rescue satellite-aided tracking service, COSPAS/SARSAT, provided by Canada, France, the United States, and the Soviet Union, was responsible for saving over 400 lives, bringing the total number of lives saved through this program to over 1,600. International participation in

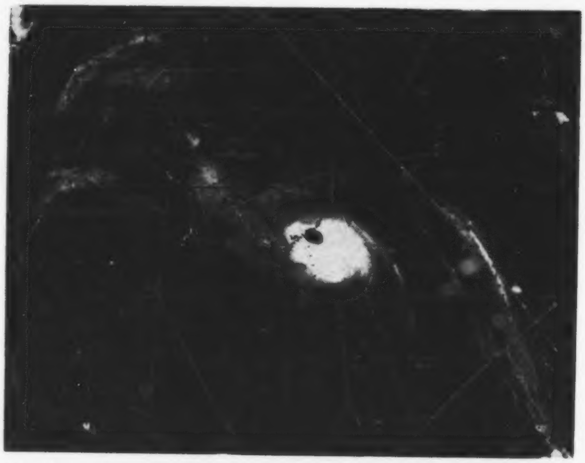
COSPAS/SARSAT continues to grow. At least 23 nations are currently participating or have declared their intention to participate.

Pan-Pacific Educational and Cultural Experiments by Satellite. In a cooperative agreement with NASA and Commerce's fourth component involved with space activities, the National Telecommunications and Information Administration (NTIA), NOAA has loaned its spare GOES-3 satellite for use by Pacific island nations through the Pan-Pacific Educational and Cultural Experiments by Satellite (PEACESAT) project to reestablish satellite communications service to the Pacific areas. Begun in 1971, PEACESAT used a retired NASA experimental satellite to provide two-way, voice-and-data services accessed by small, affordable, Earth stations in the Pacific Basin region. These services provided otherwise unavailable educational, medical, cultural, and emergency communications to more than 100 sites in 22 countries.

NOAA moved GOES-3 to 176 degrees West longitude from 129.9 degrees West longitude in June 1990. PEACESAT is controlled for NOAA by NASA from the Kokee Park Geophysical Observatory on Kauai, HI. NTIA will coordinate user operation of the satellite.

Argos. Service Argos Inc., which operates the processing centers for the Argos Data Collection and Platform Location System, focused its activities on expanding services.

Argos is provided by the French Space Agency for flight on NOAA polar orbiting satellites. Improvement of user services included upgraded software that enables the user to interact more closely with the processing centers. A new data link was also established between the U.S. and French processing centers that increased transfer speed and added full redundancy. The 1990 North American Users Conference provided users an opportunity to exchange information on many environmental applications. In 1990, more than 1,500 Argos platforms were deployed by more than 25 countries. The Argos system is used by NOAA to track the drift net fishing vessels of Japan, Taiwan, and South Korea as part of the Drift Net Act of 1990. Using Argos, several vessels were found to be outside legal areas and were intercepted by the U.S. Coast Guard.



Hurricane Hugo as the eye approached the South Carolina coast in September 1989. This photograph was produced from GOES-West satellite data.

Advanced Communications Technology Satellite. NTIA continued the planning of and preparation for experiments that will use the Advanced Communications Technology Satellite (ACTS). NASA is developing ACTS, which is to be launched in 1992, as a testbed for advanced communications technology studies. This technology will put a high-speed digital switch in the sky with the capability of establishing megabit channels to hundreds of Earth stations within microseconds. This will allow the integration of satellite communication technology with other advancing communication system technologies such as optical fiber transmission, Integrated Services Digital Networks, and mobile services. This technology could mitigate users' vulnerabilities to terrestrial telecommunications system failures and outages.

Satellite Operations and Support

Atmospheric Temperature and Moisture Soundings. The years 1989 and 1990 mark the 10th and 11th years of operational atmospheric sounding production from NOAA's polar-orbiting satellite system. These soundings are used by both the military and civilian meteorological communities as input to numerical weather forecast models. Numerous requests for sounding data and science software/techniques, from both military and civilian researchers were honored during this period. Preparations are under way for the development of the next-generation operational sounding system which will implement new science needed for the NOAA-K satellite instrumentation, which includes an advanced microwave sounder. Like the NOAA satellite series, the data from the Special Sensor Microwave/Temperature (SSM/T) instrument onboard the Defense Meteorological Satellite Program (DMSP) polar-orbiter were operationally processed into soundings. The use of data from the Special Sensor Microwave/Imager (SSM/I), also onboard the DMSP spacecraft, combined with the SSM/T data is being explored to improve the soundings. Upgrading of the DMSP sounding science to be consistent with that developed for NOAA satellites is in progress. Products from the DMSP satellites are operationally archived and distributed under the Shared Processing agreement between NOAA and the Department of Defense (DOD). Development of the next-generation geostationary satellite series (GOES-I/M) sounding product processing system is currently under way. This system will provide temperature and moisture sounding information for the NOAA National Meteorological Center (NMC) Regional Forecast Model and images of atmospheric stability and moisture to the NOAA National Severe Storms Forecast Center (NSSFC) and the NOAA National Hurricane Center (NHC).

VAS Applications. VAS (Visible-and-Infrared-Spin-Scan-Radiometer Atmospheric Sounder) data were used operationally by all of the NOAA National Weather Service National Centers (the National Meteorological, National Severe Storms Forecast, and National Hurricane Centers). Imagery of VAS-derived atmospheric stability and moisture parameters were used by NSSFC in defining outlooks and watch areas for severe weather. Imagery and a special VAS-derived Deep Layer Mean (steering current) analysis were used by the National Hurricane Center in the monitoring and forecasting of hurricanes (including Atlantic, Gulf of Mexico, and Caribbean Basin storms) which affect the United States. Imagery, satellite-derived wind fields, and moisture analyses were used by National Meteorological Center in both the global forecast models and national forecasting programs.

GOES-Tap. GOES-Tap, a program enabling users to acquire high-quality satellite imagery over telephone data circuits, continued to expand. Presently, there are approximately 350 primary users and over 500 secondary users of GOES-Tap data. These users consist primarily of National Weather Service (NWS) field forecast offices, but also include the Department of Transportation's Federal Aviation Administration (FAA), other civilian agencies (both State and Federal), DOD, private companies, universities, and the media. A significant number of high schools have also started receiving NOAA satellite images via GOES-Tap. GOES-Tap data consists of visible and infrared facsimile images from the GOES and NOAA satellites, Geostationary Meteorology Satellite (Japanese), and Meteosat (European) spacecraft. During 1990, NOAA expanded its suite of available NOAA polar satellite products accessible to NWS field offices. In addition, high-resolution polar imagery is now gridded and contains a machine-readable identification code.

Hurricane Operations. GOES continues to carry the major load in positioning and estimating the strength of tropical cyclones outside of the aircraft reconnaissance areas for the western Atlantic, Caribbean Sea, Gulf of Mexico, and the eastern Pacific. Meteosat was used to supplement GOES in the far eastern Atlantic Ocean. Within the aircraft range, satellites still play a major complementary role to the aircraft. The satellite provides continuous monitoring for early detection of change while the aircraft provides precise spot observations.

In the Eastern Hemisphere (that is, the western Pacific and Indian oceans), the NOAA polar orbiters provide the essential coverage for tropical cyclone monitoring. The NOAA data are used in providing position and intensity estimates for the U.S. Joint Typhoon Warning Center in Guam and for foreign meteorological services, as part of the World Weather Watch program of the World Meteorological Organizations (WMO).

Development continued on the DMSP SSM/I (the Defense Meteorological Satellite Program Special Sensor Microwave/Imager) to extract usable peripheral wind and precipitation measurements. The SSM/I radar-like presentation could be critical in a few cases, not only for superior positioning of weak systems, but also to detect wall cloud changes concealed from GOES by the cirrus canopy.

Satellite-based Fire Alarms. The National Geophysical Data Center of NESDIS (the NOAA National Environmental Satellite, Data, and Information Service), in partnership with the Department of the Interior's National Park Service and Bureau of Land Management, has contracted with NASA to develop a prototype operational system for using the NOAA Advanced Very High Resolution Radiometer (AVHRR) for automated early detection of wildfires.

Wildfires caused great damage in 1988 and 1989. AVHRR thermal data can be used to detect fires during the day and night. The satellite data will be used to complement existing programs to help improve early detection of such fires. The techniques are scheduled to be tested during the 1990-91 fire seasons, for possible later operational implementation.

Besides providing a service to managers of public lands, these techniques have possible commercial applications and can be used to help monitor the global environment. For example, the Food and Agriculture Organization of the United Nations is interested in implementing the technology, once it becomes operational.

Volcano Hazards Alert Plan. The NOAA Volcano Hazards Implementation Plan became effective in 1989. This plan is designed to use NOAA satellite data and trajectory models to monitor volcanic ash clouds and forecast their movement in air space controlled by the FAA.

GOES and NOAA data are used to define the horizontal and vertical extent of ash, as well as its direction and speed of movement. Multispectral techniques are under development and evaluation, to monitor ash plumes which are semi-transparent to the visible or infrared spectrum. The Alaskan Mt. Redoubt volcanic eruptions in late 1989 and 1990 have provided excellent data for improving these ash plume forecasts.

CoastWatch. In 1989, NOAA's CoastWatch support was upgraded to operational status. The Ocean Product Center is a multi-line office NOAA facility supporting NOAA's operational, oceanographic, and marine meteorological needs. The Ocean Product Center serves as a focal point for delivering high-resolution, satellite-derived, sea-surface temperature imagery, meteorological fields, and ocean feature information electronically in near real-time to NOAA facilities located in U.S. coastal areas. Research and development for the Great Lakes and the Chesapeake Bay was initiated in 1990. An automated NOAA AVHRR Image Mapping System was completed and a prototype was used to automatically map AVHRR sea-surface temperatures for use by the National Marine Fisheries Laboratory at Beaufort, NC.

Scientists used Government-developed, tailored software on a low-cost, personal-computer-based workstation to interactively extract environmental information to support Federal and State decisionmakers and researchers responsible for managing coastal living resources and ecosystems. CoastWatch is a project managed within NOAA's Coastal Ocean program, which will eventually cover all marine areas within the U.S. exclusive economic zone. In 1990, prototype CoastWatch activities were brought together into a comprehensive program focused on the southeastern U.S. coastal waters. The Interactive Marine Analysis and Forecast System and the NOAA Ocean Communications Network were components of the program.

The Center for Ocean Analysis and Prediction was formed in 1989 to serve as a NOAA facility for developing and disseminating oceanographic products and services in support of NOAA's mission.

The National Ocean Service operates three national ocean centers: the Navy/NOAA Joint Ice Center, the Ocean Product Center, and the Center for Ocean Analysis and Prediction. In the case of the Joint Ice Center, satellite imagery represents the primary data source used to meet this Nation's requirements for Arctic, Great Lakes, and Antarctic analyses of sea/lake ice conditions, for both civil and military users.

Strategic Assessment Program. This program used NOAA and NASA satellite data to produce analyses which describe the physical and biological conditions within estuaries, adjacent coastal waters, and the continental shelf. Satellite images were acquired and analyzed to determine the following: the location and movement of estuarine plumes and shelf/slope fronts; the interactions and exchanges of water between estuaries and coastal oceans; and the distribution and concentration of primary productivity zones. The analyses produced by this program are used by coastal managers to help monitor and assess the environment within which living marine resources must survive.

Fisheries Enforcement. In cooperation with the National Marine Fisheries Service (NMFS), the National Ocean Service began providing satellite imagery and other environmental data to the NMFS Enforcement Offices in Sitka and Juneau, AK. These offices used the information to determine the most likely location of illegal foreign fishing activity. U.S. Coast Guard surveillance aircraft and ships were guided to these locations and reported an increase in the number of at-sea apprehensions.

Aviation Applications. Research continues at NESDIS on the detection of aviation hazards such as thunderstorm downbursts, fog, and clear-air turbulence. Case study analyses have shown that several parameters obtainable from GOES soundings can help to isolate areas where a high risk of downbursts is present. The use of two infrared channels from GOES was found useful in the detection of fog and stratus at night, when other techniques often fail. The quantitative brightness difference between these channels appears to be related to the thickness and subsequent clearing or dissipation of fog. Satellite image analysis techniques, organized into a "decision tree" methodology, are being used to detect and forecast areas of clear-air turbulence. A forecast product, the Turbulence Index, was developed and is being used in NOAA, by the U.S. Air Force, and by the Canadian Meteorological Service.

Rapidly Developing Storms. Investigation of weather patterns, including satellite and surface observations, associated with storms that intensify or develop rapidly was the focus of a special observational program, Experiment on Rapidly Intensifying Cyclones in the Atlantic (ERICA), conducted by NOAA, Department of the Navy, and academic meteorologists. Most of these storms occur along the East Coast of the United States where observations are ordinarily limited. Satellite observations appear to be the key to better forecasting of these events that are of great concern to the coastal and marine community.

NESDIS also began developing a procedure for classifying mid-latitude winter cyclones in the Atlantic Ocean. Preliminary results show significant improvement over existing techniques for estimating the central pressure of systems.

Precipitation. Improvements to the operational satellite rainfall estimation technique continued. A study of rain events, where rainfall estimates were either over- or underestimated, showed that large convective storm clusters are not as dependent on the environmental moisture amounts as are smaller storms. Further work looked at the movement of convective systems that produce flash floods, showing most move toward the west or southwest. Long tropical moisture plumes that can be seen in GOES water vapor data are being examined as another diagnostic tool for heavy precipitation forecasting. An objective, automated method to produce convective storm precipitation estimates, developed by NASA, was tested. This technique will assist in simultaneously monitoring the whole United States, instead of only one or two areas. This will help insure that no potential heavy precipitation event would be missed, and will allow the meteorologists to concentrate on estimating precipitation and localizing forecasts. Heavy snowfall associated with mid-latitude storms was also under study. These events are usually convective and appear to have many of the same developmental characteristics that are displayed by the summertime, flash-flood producing convective systems.

Aerosols Optical Thickness. In January 1990, NESDIS made its experimental aerosol optical thickness product operational. The experimental production began in July 1987. Contour charts and digital tapes have been archived at the National Climate Data Center since the summer of 1989. The aerosol optical thickness is derived from reflected solar radiation measured by channel 1 of AVHRR. The observed "cloud-free" radiances are compared with radiances computed from a radiative transfer model of the atmosphere/ocean system. The accompanying figure shows a portion of the global contour map for the 4-week period ending July 26, 1990. The largest concentrations of aerosols are from dust blown off the deserts of Africa and Saudi Arabia and from haze emanating from the eastern United States and western tropical

South America. The air over the oceans of the Southern Hemisphere appears to be much "cleaner" than over the Northern Hemisphere, consistent with more land surface area and industry in the latter.

Satellite Applications Training. With increasing domestic and international awareness of the value of satellite information in weather and oceanographic analysis and forecasting, demand for training in satellite applications soared. Almost 100 courses and workshops taught or coordinated by NESDIS, training almost 2,000 forecasters and others in the National Weather Service, DOD, and overseas weather services and in weather-dependent agencies. Training topics included synoptic and mesoscale analysis, heavy rainfall, water-vapor imagery interpretation, numerical-model initial analysis, and tropical meteorology, oceanography, and agroclimatic applications.

NESDIS has completed self-study training modules. Two script-slide programs (basic polar interpretation and local winds) and the first volume of a tropical-cloud-and-weather-system workshop were completed. Work has begun on additional slide programs, several videotapes, and at least two training interactive video-disc learning programs.

Procedures for publishing Satellite Applications Information Notes were reestablished. At least six Notes, designed to disseminate new satellite techniques to National Weather Service operations staff in a timely manner, were published.

Millimeter Wave Frequencies. The National Telecommunications and Information Administration (NTIA), another of the four components of the Department of Commerce involved with space activities, continued to study propagation effects at millimeter-wave frequencies on Earth-space paths. Measurement of these millimeter-wave characteristics, employing satellite propagation beacons, will allow NTIA to more effectively analyze higher level atmospheric effects on millimeter-wave system performance. The geographical and seasonal dependence of propagation effects, important for Earth-space communications, continue to be studied.

Space Programs Support. Precisely synchronized Earth stations are extremely important to NASA's Deep Space Network used for space navigation. Commerce's National Institute of Standards and Technology (NIST) assisted the NASA Jet Propulsion Laboratory in synchronization of NASA stations in the United States, Australia, and Spain.

The Hubble Space Telescope's High Resolution Spectrograph will have onboard calibration from a platinum spectrum. Measurements using this spectrum were incorporated into the calibration codes for the spectrograph and used in the data reduction obtained with the International Ultraviolet Explorer satellite.

Synchrotron radiation at the NIST Synchrotron Ultraviolet Radiation Facility is being used to calibrate spectrometer sensitivity over a wide range of wavelengths. Users of this calibration service included scientists from Government laboratories and academic institutions. Detector calibrations were also provided and used by space scientists during flight preparation.

Astronomers at NIST are participating in the scientific and technical design of several future NASA scientific satellites including the Advanced X-ray Astrophysics Facility, the Far Ultraviolet Spectroscopic Explorer, and the Space Telescope Imaging Spectrograph.

NIST is involved in the National Aero-Space Plane program as a member of the instrumentation team. There are many measurements required by this program which are unprecedented and will need substantial development and testing.

Design and construction of a new leak calibration system for NASA continues. The retention or exclusion of gases and fluids is important for the operation of many space systems and critical for manned systems because many of the gases are toxic.

NIST is working on the control system for NASA's Flight Telerobotic Servicer (FTS). The FTS is a two-armed robot which will be used to build and maintain Space Station Freedom. The sensory interactive capabilities being developed will allow the FTS to evolve from teleoperation toward autonomous operation which is necessary for docking, assembly, and inspection tasks.

NIST developed the capability of executing, in a matter of minutes, enormous mathematical codes for correcting short period fluctuations in a satellite trajectory which are caused by the irregularities in the gravity field of Earth. Such calculations are used to predict the extra amount of fuel needed to maintain the designed trajectory.

Cryogenic flowmeters are being developed and tested for use in the fuel supply system of the space shuttle and liquids-handling systems of satellites. Work on regenerators for pulse-tube refrigeration devices capable of operating below 30 degrees kelvin continues. Research, calibration services, and standards are provided to allow quantification of mixtures of gases used in space shuttle ground support systems.

Commercial Space Support

Office of Space Commerce. The Office of Space Commerce (OSC), the newest of four components of the Department of Commerce involved with space activities, was formally established in 1988. It is the Department's principal unit for the coordination of commercial space-related issues, programs, and initiatives. In this capacity, OSC promotes private sector investment in space activities by collecting, analyzing, and disseminating information on space markets and conducting workshops and seminars to increase awareness of commercial space opportunities. OSC also assists commercial space companies in improving their understanding of how to do business with the U.S. Government and foreign organizations, and promotes the export of space-related goods and services. The Office represents the Department in the development of U.S. policies within the National Space Council and in negotiations with foreign countries to ensure free and fair trade internationally in the area of space commerce. Finally, OSC works within the U.S. Government to seek the removal of legal, policy, and institutional impediments to space commerce.

In the area of information analysis and dissemination, OSC recently completed a report on financing commercial space ventures called *Commercial Space Ventures: A Financial Perspective*. This document addressed the major hurdles faced by private entrepreneurial firms as they attempt to obtain financing for their ventures. OSC, in cooperation with the Department's Office of Economic Affairs, also prepared a compendium of space business statistics called *Space Business Indicators*, which provides important business information such as the annual revenues generated by the commercial satellite or expendable launch vehicle industry.

OSC also assisted commercial space companies in doing business with foreign governments and companies. In response to requests from both established and entrepreneurial aerospace companies, OSC worked to ensure fair treatment in major international satellite and launch vehicle contracts. OSC, working with the U.S. and Foreign Commercial Service, helped numerous U.S. firms to obtain important market information and establish business relationships with foreign governments. OSC also initiated a seminar series designed to introduce U.S. businessmen and women to their counterparts in foreign countries. These seminars have resulted in new and expanded business opportunities for U.S. participation. In addition, OSC hosted several meetings of government officials and private sector telecommunications representatives to discuss the technical and commercial viability of a new concept for digital audio broadcasting from satellites. This support resulted in an increased interest in both the technology and its potential business applications.

OSC played a key role in negotiating an international trade agreement in commercial launch services with the People's Republic of China. OSC prepared key U.S. position papers and participated actively in negotiations with Japan on satellite procurement. In addition, OSC is negotiating with the European Space Agency to establish "rules of the road" for worldwide commercial launch services and pricing. Also, OSC represented DOC in the Japanese Space Cooperation talks.

OSC worked with the National Space Council to revise and update the National Space Policy in 1989. In 1990, OSC represented the views of the Department in National Space Council reviews of commercial space launch policy, national space launch strategy, and commercial space policy implementation. The commercial space launch policy provided the framework for a Presidential decision allowing a U.S. firm to participate in the design of a commercial spaceport on the Cape York Peninsula of Australia that proposes to use Soviet manufactured launch vehicles.

Commercial Space Support and Technology Transfer. Members of the National Institute of Standards and Technology (NIST), Commerce's fourth component involved with space activities, participated in a number of Governmental and private groups related to the commercial development of space. These included the Secretary of Commerce's Commercial Space Advisory Committee, the National Security Council Space Policy Working Group, the National Academy of Sciences Micro-gravity Facilities Study, and the American Institute of Aeronautics and Astronautics—NASA Commercial Programs Strategic Plan Working Group.

NIST is developing measurement methods and techniques for materials processing in the microgravity environment. In order to test these techniques, NIST participated in the first NASA Centers for the Commercial Development of Space sub-orbital flight. This work was performed in association with the Micro-Gravity Materials Processing Center of the University of Alabama—Huntsville.

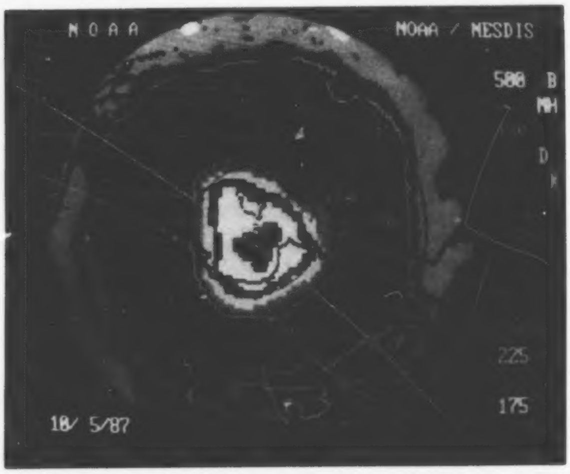
In order to assist future private sector utilization of the shuttle external tank, a numerical method to determine the aerodynamic drag and torque in low-Earth orbit was developed. The object of the investigation was to determine the minimum thrust and fuel requirements for an exterior propulsion package used to avoid re-entry on the critical first orbit and to place the tank in a short-term stable orbit.

Research Applications

The Climate and Global Change Program. Used at first to locate and track weather phenomena by providing images of clouds and storms, the operational satellites have developed into sophisticated remote sensing platforms for both operational and research purposes. While designed primarily for weather observations, the versatile instruments onboard provide quantitative information on a number of climate variables. They are providing an unparalleled set of continuous environmental observations for researchers studying global climate change.

Examples of some of these observations include the following:

- Since 1969, global atmospheric soundings of temperature and moisture. Significant improvements in these soundings occurred in 1979 with the introduction of the TOVS (Television-and-Infrared-Operational-Satellite Operational Vertical Sounder).
- Since 1970, global sea surface temperature. High quality observations began in 1981 with the launch of a five-channel AVHRR.
- Since 1966, maps of snow cover, showing for example that the summer snow cover over the Northern Hemisphere this past summer was the lowest of the entire 25-year satellite record.



Example of the total ozone amount, showing the "ozone hole," over the Antarctic for October 1987. This black-and-white photograph was converted from the original false-color photograph.

- Since 1972, maps of sea-ice cover on the oceans.
- Since 1982, weekly global maps of vegetation index, a measure of the vigor and density of green vegetation.
- Since 1974, quantitative estimates of the global distribution of Earth's albedo and emitted longwave radiation, the two major components of Earth's radiation budget.
- Since 1985, the global distribution of the total amount and vertical profile of atmospheric ozone.

Because they must meet the operational requirements for continuous data, the NOAA satellites have no gaps in the long-term monitoring record so critical for measuring global change.

While the NOAA satellite products can be applied to a number of problems in climate research, much remains to be done to produce research quality data sets. In particular, major reprocessing efforts are necessary from time to time. As improvements were made in the science algorithms, the data processing system was changed. Because the satellite's visible radiation sensors tend to degrade in orbit and there is no onboard calibration, the record of the changes can only be estimated from special analyses. NASA and NOAA are currently cooperating on a major effort to reprocess the entire long-term archive of three major instruments: the Advanced Very High Resolution Radiometer (AVHRR), the TOVS, and the GOES Visible and Infrared Spin-Scan Radiometer.

Ozone. A new physical processing procedure for determining total ozone from the TOVS polar sounders provided a potentially invaluable source of new data on the ozone field. Real-time operational TOVS information on the 1990 Antarctic ozone hole was made available to interested parties by NOAA. These data indicated that the 1990 ozone hole developed from as early as mid-August into what appears to be a major ozone depletion. Earlier this year, record low ozone amounts over the Arctic region were recorded by TOVS. Low north and south polar ozone values contributed to an overall downward trend of global ozone since 1979 which, as determined from the new TOVS procedure, is estimated to be on the order of 4 percent. This has to be evaluated with respect to natural variability.

Global Vegetation Index. The experimental Global Vegetation Index (GVI) product of NOAA provided a one-per-week view of Earth's vegetation since May 1982. The GVI is derived from daily data acquired by the AVHRR onboard the NOAA polar-orbiting series of satellites with local orbit times in the early afternoon. A weekly composite is produced that uses daily visible and near-infrared data to screen the data of each map cell such that the "greenest" or most "cloud-free" data of each week are retained for each map cell. The Normalized Difference Vegetation Index (NDVI) is also computed for each map cell, based on the composited visible and near-infrared data, and is included in the weekly product that is available in several map projections. An experimental, quality-controlled, biweekly NDVI product has been produced from the GVI data for 1985 through 1989 in a cooperative research effort with the U.S. Geological Survey (USGS) Earth Resources Observation System Data Center. The experimental NDVI product was distributed to several scientists for evaluation of its potential use in Global Climatic Models. Research efforts continue to improve the quality and use of the NDVI data in Global Circulation Models and as direct indicators of year-to-year and regional variations in climatic conditions.

Snow-Cover Observations. NESDIS continues to support its operational snow-cover mapping program. Weekly analyses, using GOES, Meteosat, and NOAA polar-orbiting satellite data, were prepared for the Northern Hemisphere showing the boundary between snow-covered and clear ground. Techniques are being evaluated to blend microwave data (from the DMSP SSM/I) into the operational snow-cover mapping program. These weekly charts were provided to the National Weather Service for use in their global forecast models and stream flow models, and also to university researchers and private companies. These data, produced since 1966, comprise a valuable climatic monitoring resource.

Generic Cloud Algorithms. Under development is a multichannel algorithm for cloud detection. The objectives are to provide a method for detecting clear pixels for remote sensing of surface parameters, and to provide a means of estimating cloud amount and other cloud properties useful for diagnosis and initialization of climate and weather prediction models. The technique uses all five channels of Global Area Coverage resolution AVHRR data. Cloud distributions from initial test results look realistic.

Sea-Surface Temperature Measurements. Since 1981, sea-surface temperature (SST) measurements have been provided in real time on a global basis at a resolution of 4 kilometers using the multichannel digital data (visible, reflective-, and thermal-infrared) obtained from the AVHRR instrument. A correction must be made for atmospheric attenuation by water vapor which is both highly variable and temperature dependent. Until 1990, a linear model was applied that assumed this correction was a constant multiplied by the radiative temperature difference. A non-linear model was implemented in March 1990 in which the constant became an explicit function of the scene temperature and the radiative temperature difference. Results show that the non-linear SSTs are more accurate than the linear SSTs both under very dry atmospheric conditions when the radiative temperature difference is quite small and under very moist conditions.

The National Ocean Service (NOS) is using satellite imagery to monitor SST as part of the 106-Mile Deepwater Municipal Sludge Dump Site project, which is carried out jointly with Environmental Protection Agency and the U.S. Coast Guard. SST imagery is used for the identification of surface water masses, as an aid in the interpretation of the tracks of drifters released at the site, and for monitoring significant physical features such as the Gulf Stream and warm-core rings.

Mesoscale and Severe Storm Research. NESDIS has a research project under way to improve the use of satellite-derived soundings for forecasting convection and severe thunderstorms. A technique has been developed to enhance infrared satellite sounding measurements to probe the precursor conditions needed for convective storms to form. These infrared measurements are used to detect temperature and water vapor variations that define small-scale airmass characteristics, better depicting these characteristics and their inter-relationships as producers of intense thunderstorms.

Tropical Storm Research. At NESDIS a research project is under way to understand and forecast tropical cyclone genesis and intensity using geostationary satellite data. Digital satellite data have been used to study the distribution, intensity, and time evolution of deep convective cloudiness associated with this genesis process. Results show a convective maximum, followed by one or two days of decreased but more organized convective activity, preceding the tropical-storm stage.

National Marine Fisheries Service Research. Satellite oceanic remote sensing continues to play an important role in National Marine Fisheries Service research. Satellite observations provide synoptic information needed for studying the effects of the ocean environment on the abundance and distribution of fish populations.

The Alaska Fisheries Science Center, in collaboration with the Pacific Marine Environmental Laboratory and various academic institutions, is conducting a Fisheries Oceanography Coordinated Investigation of the Gulf of Alaska. One objective is to determine the effects of the ocean environment on the walleye pollock. Satellite measurements of ocean environmental parameters are used in conjunction with data collected by ships and aircraft to describe and eventually predict the distribution of the parameters that may adversely affect the survival of the pollock.

The Alaska Fisheries Service Laboratory completed testing of a prototype satellite tracking system that is used to monitor the movement of several hundred radio-tagged salmon in remote Alaskan waterways. The data received through the satellite allow fisheries scientists to determine the migration patterns and distribution of the salmon. This information will be used for management of salmon stocks in transboundary rivers as required by the Pacific Salmon Treaty between the United States and Canada.

Scientists from the National Marine Mammal Laboratory also are using a satellite tracking system to monitor the movement of marine mammals tagged with radio transmitters. These data are used to study diving habits, to locate feeding grounds, and to obtain information on the environmental conditions in the grounds. The satellite platform used in this study is the NOAA polar orbiter with data transmission provided by the Service ARGOS Inc. Two projects in 1989 were conducted in collaboration with Soviet and Japanese scientists.

The Southwest Fisheries Center is using satellite infrared imagery and ocean color data to determine the distribution and migration patterns of albacore tuna and Pacific mackerel in coastal waters. Results of these studies show that the availability and migration of albacore tuna is related to the strength and structure of the plume of cool, turbid water flowing off Point Conception in California. Studies also show that the Pacific mackerel during autumn months live in the part of the plume that extends into the Santa Barbara Channel. The location of the plume, which can be determined easily with satellite imagery, assists commercial fishermen in locating concentrations of tuna and mackerel. The Center also provided technical assistance for developing fisheries satellite remote sensing programs in Canada, Portugal, and Taiwan.

Northeast Fisheries Center scientists are using satellite data along with more traditional data to describe near real-time and long-term variations in marine environmental conditions affecting the fisheries in their area. The Northeast Area Remote Sensing System, an association of Government (including the Center), academic, and private institutions, provides a means of information exchange and a support base for meeting regional satellite and aircraft remote sensing data needs. The system also helps maintain a communication network between users of remote sensing data and its source.

In the Southeast Fisheries Center, NOAA polar orbiter satellite data were used to direct a research vessel to a region of cold-water upwelling near the Yucatan Peninsula. The cruise was a joint effort of the United States and Mexico to sample Mexican coastal waters for ichthyoplankton with target species of Spanish and king mackerel. Satellite images were processed in Mississippi, compressed, and sent digitally through the International Maritime Satellite Organization's communications network directly to a personal computer onboard the ship, where software allowed shipboard users to display the image in color and to select areas of interest. This technique was also used to send compressed satellite thermal images to vessels with different research objectives in other parts of the Gulf of Mexico.

High-Performance Aerospace Materials. The National Institute of Standards and Technology (NIST) is studying the physics and chemistry of the combustion of metallic materials in high-pressure/high-temperature oxygen environments which occur in the space shuttle main engine. Frictional generation of oxides is being used to estimate actual temperatures experienced by components.

The performance characteristics of state-of-the-art heat exchangers for use in high-mach aircraft are being determined. Fuel used in these high-performance aircraft is preheated before injection into the engines by absorbing through these exchangers the heat developed by aerodynamic friction; this absorption also helps cool the skin of the vehicle. Development of predictive models is an important component of this research.

Methods of generating slush hydrogen and measuring its flow and storage characteristics are being studied. Slush hydrogen provides increased energy density and cooling capacity for use in high-performance aircraft and rockets.

A unique capability to study the thermal conductivity of insulating materials for application in advanced aircraft and rockets was developed. This facility includes systems needed to study classical thermal conductivity as well as heat flow with extremely large temperature differences imposed.

Research is being conducted under Air Force sponsorship on the use of composite materials containing solid lubricants in mechanical components for space satellites. The aim is to develop a fundamental understanding of self-lubricating composites and to recommend materials for actual systems. Recommendations have been made on hardware design and production procedures.

Research is being directed toward the development of techniques for synthesis of finely divided gold catalysts on conductive ceramic supports for alkaline fuel cells used in aerospace applications requiring long life-time and high efficiencies. Results to date have demonstrated properties superior to conventional Teflon supports.

Work is currently under way to establish the feasibility of using high-temperature ceramic superconductors as radiant heat instruments for measuring temperature on missions to distant planets. NIST's unique high-temperature X-ray diffraction capability was used to study a series of high-temperature superconducting ceramic film-on-substrate samples.

Theoretical studies and numerical calculations have been carried out to provide guidance and interpretation for a series of planned space experiments on directional solidification of metal alloys in microgravity. The objective is to make quantitative measurements of coarsening which are not disturbed by the density-driven fluid flows in normal gravity. Several studies have focussed on topics relevant to crystal growth experiments that are to be performed onboard the space shuttle.

NIST's unique synchrotron-based X-ray capabilities for nondestructively imaging atomic scale defects has been used to study single crystal materials of interest to the national space effort. The results are providing insight into ways in which these materials can be processed (in space as well as on Earth) to increase their performance.

Space Sciences Research. A comprehensive database of evaluated atomic spectroscopy data, covering all atoms and ions of astrophysical interest, is under development for general use of space research groups. The database will be compatible with the NASA astrophysics data system and will be incorporated into appropriate existing NASA databases.

The photoabsorption spectrum of nitrogen was measured with a new ultrahigh resolution spectrometer at the NIST Synchrotron Ultraviolet Radiation Facility. NIST measurements resolved long-standing discrepancies between plasma density measurements of the F2 region of the ionosphere by various remote-sensing techniques.

Scientists at NIST and Oxford University have for some years been doing very accurate spectroscopic measurements of infrared and far-infrared spectral frequencies of upper atmospheric and interstellar molecules. These frequency measurements provide the basis for searches for such molecules thus benefitting NASA programs in both radio astronomy and aeronomy. Tables of spectral frequencies generated by this program also serve as calibration standards for the various spectrometers used to study the upper atmosphere.

NIST continues assisting NASA investigators in determining accurate atmospheric parameters and elemental abundances of hot stars by providing the results of sophisticated model calculations of stellar atmospheres. A stellar parameter is being developed which provides sufficiently accurate constraints on the theory of stellar evolution that the effect of the physical uncertainties can be evaluated and eventually removed.

NIST and the Goddard Space Flight Center have several projects under way to measure microwave radiation from stars. They have completed a survey of stars in close binary systems and are studying nearby stars less massive than the sun.

NIST astronomers are pursuing a program to measure surface magnetic fields on stars cooler than the sun. This work interprets absorption lines with a radiative transfer code that includes optically thick absorption and a detailed model for the atmosphere of the star. Surface magnetic fields have been measured in 50 stars.

NIST astronomers have developed a Doppler imaging technique to determine the location and sizes of bright and dark regions on the surfaces of rapidly rotating stars. Conventional imaging cannot provide such information because the regions are smaller than the diffraction limitation of existing telescopes. The work is based on the analysis obtained with the International Ultraviolet Explorer satellite.

NIST performed analytical procedures on biological samples collected from separation experiments onboard the space shuttle and prepared reviews of separation science in the low-gravity context. NIST also performed modeling studies in gravitational and space biology and provided leadership in the physical analysis for low gravity and simulated low gravity.

Under the NASA Crustal Dynamics Project, NIST is working to determine worldwide tectonic plate motions and Earth's rotation. The model calibrates the atmospheric transmission delay caused by water vapor so that the accuracy of geophysical and astronomical studies based on microwave distance measurements through the atmosphere can be improved. A more accurate determination of the displacement rate across the San Andreas fault system in California was made from satellite laser range data.

A spectral irradiance intercomparison and instrument evaluation was conducted with NASA, the Naval Research Laboratory, NOAA, and two members of the European Space Agency. The main purpose was to put future radiometric space measurements on a common base. This project was useful in solving major measurement problems before the instruments were launched; the measurement evaluation maximized the success of the mission.

Models are being developed to predict the dynamic structure of flames in reduced gravity. Results indicate that experiments at low pressures and normal gravity can provide information on combustion phenomena at reduced gravity. A theoretical model for predicting flame and smoldering of a cellulosic (for example, paper) material in a microgravity environment using factors experimentally measured in normal gravity was developed. NIST is comparing NASA's and NIST's material-flammability screening tests and studying the relationship between them and flammability in microgravity.

Atmospheric Sciences Research. NIST has several projects related to the problem of ozone depletion of the upper atmosphere and the greenhouse effect. Molecular spectroscopy is used to provide the data for monitoring molecular species present in trace amounts in Earth's atmosphere. NIST and NOAA are collaborating on measurements of concentrations of hydroxyl, water, ozone, chlorine, oxygen, and some nitrogen oxygen compounds. Data from these and other measurements are being compiled into database tables which will enable atmospheric modelers to predict equilibrium conditions for the atmosphere and its chlorine pollutants.

The spectra of carbon dioxide, chlorine dioxide, and cyanogen were investigated under high resolution. Subtle perturbations such as temperature- and pressure-dependent mixing of spectral lines have a strong effect on the interpretation of the observed spectra in terms of appropriate theoretical models.

In a joint program with the Smithsonian Astrophysics Observatory, NIST scientists are making laboratory determinations of the effect of pressure on the spectroscopic linewidths of upper atmospheric molecules. These laboratory measurements are needed to interpret NASA's satellite and balloon measurements of atmospheric constituents.

NIST scientists continue their data evaluations and laboratory measurements in support of the NASA Upper Atmosphere Research program. They participated in meetings of the NASA panel for data evaluation to prepare a new evaluation of chemical kinetics and photochemical data for use in modeling the chemistry of the stratosphere. They measured the rates of the chemical reactions controlling the atmospheric lifetimes of replacement compounds for the fully halogenated fluorocarbons.

NIST is engaged in extensive calculations of electron precipitation events in Earth's atmosphere (auroras, substorms, magnetic storms) which are important in magnetospheric processes and interactions with the upper and middle atmosphere. Because direct measurements of the precipitating electrons are difficult, much experimental evidence is based on indirect measurement from which initial electron distribution and the ionization profiles in the atmosphere are deduced.

Geosat. During the past five years, the U.S. Navy altimeter satellite Geosat has provided nearly continuous measurements of global sea level, wind speed, and sea state. Under agreement with the U.S. Navy, the NOAA Geosat project prepares and distributes raw data and products from this mission. Several hundred scientists in more than 40 institutions and countries receive geophysical data records on a regular basis.

Though the Geosat satellite failed in January 1990, ending a long-standing flow of altimetric data, the interest in geophysical applications of the data continued to grow steadily. Launched in March 1985, Geosat substantially exceeded its expected three-year life span. The NESDIS National Geophysical Data Center (NGDC) continued, along with the NESDIS National Oceanographic Data Center, to provide this community of users with publicly available Geosat data.

The Geosat project is a key element of the NOAA Climate and Global Change program, in particular, the NOS sea level portion. Satellite altimetry is the only way to obtain global and detailed determinations of sea-level variations such as those associated with El Niño. In addition to providing data for oceanographic research, the Geosat mission has enabled the first operational monitoring of sea level over entire ocean basins. NOAA presently publishes sea-level maps of both the Pacific and Indian oceans in near-real time.

The Geosat altimeter is also being used to procure improved models of the geoid and of the gravity field of Earth's oceans. This information is fundamental to improving our understanding of Earth processes.

Global Positioning System. The National Geodetic Survey of NOS continues development of the Global Positioning System (GPS) techniques whereby moving instrumentation platforms, including ground vehicles, ships, and aircraft, were positioned by satellite to within five centimeters. This technique has been used by Texas and Washington for more rapid and economical photogrammetry. Also, the technique has been demonstrated to support airborne gravity measurements.

The computation of precise GPS orbits requires a continuously operating GPS tracking network. NGS continues use of its Cooperative International GPS Network (CIGNET) which is a global GPS tracking network. The participating stations include those in the United States, Canada, Norway, Sweden, Germany, Japan, Tasmania, New Zealand, and Australia. These data are delivered to NGS each week where they are archived, reformatted, and distributed upon request.

Solar Geophysical Data. In 1989, solar activity reached record levels and had important effects at Earth, in near-Earth space, and in deep space. The NESDIS NGDC staff collected information about the solar flares, charged particles (plasma) arriving at Earth's magnetosphere, the geomagnetic and ionospheric disturbances which resulted, and their effects on technological systems and people. During March 1989, one of the largest magnetic storms ever recorded occurred and many operational spacecraft and ground-based systems were adversely affected. During several periods of solar activity in 1989, astronauts were in orbit on the space shuttle and the Soviet space station. Also, high-altitude aircraft recorded unusually high radiation levels. NGDC is collecting data about the solar activity and its consequences and NGDC staff have taken part in scientific meetings and published papers about these events.

NGDC developed new graphical displays of satellite space environment data, ground-based correlative data, and locations of satellite anomalies. These clearly show inter-related links between anomalies and the disturbed environment.

National Oceanographic Data Center CD-ROM. The National Oceanographic Data Center (NODC) prepared a CD-ROM compact disk, "NODC Experimental CD-ROM NODC-01: Pacific Ocean Temperature and Salinity Profiles." The disk contains over 1.3 million temperature-depth and salinity-depth profiles taken in the Pacific Ocean between 1900 and 1988. This is the first in a planned series of ocean-data compact disks which will hold major portions of NODC's global data archives.

Global Monitoring. The NESDIS National Geophysical Data Center (NGDC) began its Global Change Database program, a cooperative effort with the International Geosphere-Biosphere Programme and others aimed at compilation and integration of improved databases for global environmental monitoring. Its first pilot effort, the Global Change Diskette Project, completed a prototype database for Africa in 1990, which was used to increase discussion on design and implementation of improved databases.

The program has successfully increased national and international activity in this area, bringing to NOAA and the Nation a cost-effective collection of data. A large volume of these data is derived from NOAA and other satellite technology. The database and associated software are being used by U.N. organizations in workshop and training activities relating to remote sensing and environmental data.

Earth System Data Directory. In 1990, NOAA installed the prototype NOAA Earth System Data Directory, and an on-line computer directory of NOAA data sets. The system is part of the national and international Global Change Master Directory network of data directories, that includes the directories at European, Japanese, and Canadian space agencies. The NOAA Directory contains over 100 descriptions of satellite data held in NOAA data centers and is the keystone for the NOAA Earth Observing System Data and Information System and NOAA Data Management efforts.

National Climatic Data Center Data Holdings. The National Climatic Data Center (NCDC) is responsible for the archive and distribution of much of the Nation's environmental satellite data. NCDC satellite data archives consist of data originating from NOAA operational polar and geostationary satellites, the DMSP, and certain NASA satellites. Data management, quality control, storage, retrieval, and distribution are performed at the NCDC facilities in Suitland, MD, and Asheville, NC, and also at the University of Wisconsin Space Sciences and Engineering Center. Data holdings at all locations are primarily in digital format; however, a film library which primarily contains AVHRR imagery is maintained at the NCDC Satellite Data Services Division at Camp Springs, MD. This library serve as a browse facility to support digital data selection.

International Activities

World Meteorological Organization Panel of Experts on Satellites. In November 1989, NOAA participated in the World Meteorological Organization (WMO) Eighth Session of its Executive Council Panel of Experts on Satellites. This is an advisory panel which reviews WMO satellite activities and makes recommendations pertaining to coordination of meteorological satellite programs of member states and plans to ensure continuity of observational capabilities from space.

The Panel reaffirmed the practice of free and open exchange of data for operational meteorology and climate research. The Panel encouraged satellite operators to ensure the compatibility of national satellite systems to assure continuity of coverage. The Panel recommended that the definition of operational system continuity be expanded to include maintenance. The Panel also recommended that national and international space research organizations be encouraged to accept requirements from the meteorological community stated through WMO and to give these requirements priority.

The WMO Commission for Marine Meteorology, jointly with the Intergovernmental Oceanographic Commission, reestablished the Working Group on Technical Problems to prepare an annual report on the development of the main remote sensing programs relevant to marine meteorology and physical oceanography. The group consists of an ad hoc group on oceanic satellites and remote sensing, presently chaired by NOAA/NESDIS with members from the United Kingdom, Netherlands, France, and the Soviet Union.

International Forum on Earth Observations Using Space Station Elements. In April 1989, the International Forum on Earth Observations Using Space Station Elements (IFEOS) met in Ottawa, Canada. IFEOS was created to examine technical and operational aspects of using the polar platforms of the international space station for Earth observations. As a result of a joint NOAA/NASA resolution, IFEOS was disbanded by unanimous consent. The rationale for dissolution of the group was as follows: 1) IFEOS had been successful in achieving its goals as evident in the space station partners' efforts to establish a global Earth observation system based on the polar platforms of the international space station; and 2) other international groups, primarily the Committee on Earth Observation Satellites, can effectively carry on the work of international coordination of Earth observation activities of member agencies and countries.

Coordination of Geostationary Meteorological Satellites. In November 1989, the Coordination of Geostationary Meteorological Satellites group, which serves as an informal technical forum through which independent national meteorological programs can be harmonized in order to achieve common meteorological mission objectives, met in Geneva. The group members, which include European Meteorological Satellite program, India, Japan, the United States, the Soviet Union, the Peoples Republic of China (who became a full member at this meeting), and WMO, continued their work in allocating radio frequencies for the data collection system and in standardizing formats for WEFAX (weather facsimile service) computer codes.

Committee on Earth Observations Satellites. The Committee on Earth Observations Satellites (CEOS), formed in 1984 as an outgrowth of the international Economic Summit of Industrialized Nations, serves as a coordinating forum for the overall Earth observations space community. At its April 1989 meeting, the CEOS stressed the coordinated planning required for Polar Platforms and future missions.

For the benefit of members and the international user community, the CEOS Working Group on Data defines areas for increased coordination and standardization of data management for space-borne Earth observations. Its data product subgroup coordinates standardization of user product formats. Member countries have agreed to incorporate endorsed sensor formats into ongoing data management planning. The Catalog Subgroup, chaired by NESDIS, is working on developing and promoting an approach for achieving an interoperable international catalog system. WMO is addressing a proposal by Japan on a worldwide Network for Global Environmental Monitoring from Space. Other projects include a data dictionary, networks, and distribution media coordination. The CEOS Working Group on sensor calibration and performance validation, chaired by the European Space Agency, fosters technical coordination and cooperation for space and ground segments in terms of mission parameters and sensor calibration and performance validation.

International Polar Orbiting Meteorological Satellite Group. The 1984 Economic Summit of Industrialized Nations endorsed the creation of the International Polar Orbiting Meteorological Satellite Group (IPOMS) to explore mechanisms for increased international cooperation in support of polar-orbiting meteorological satellites and to ensure continuity of these satellites.

In 1989, letters of intent concerning potential contributions to the next series of polar-orbiters were received from all IPOMS members. Notable is the European plan to provide instruments and spacecraft for morning polar orbit and instruments for afternoon polar orbit. At its September 1990 meeting in Venice, Italy, contributors were encouraged to pursue formal agreements and to plan for data access and continuity.

World Administrative Radio Conference. The Consultative Committee International Radio (CCIR), part of the International Telecommunication Union, performs technical studies that are used in the deliberations and decisions of that Union. CCIR Study Group 4 has responsibility for studies pertaining to Fixed Satellite Service, in which NTIA participates. Our participation included submission of technical material pertaining to the sidelobe characteristics of antennas used for Earth stations, participation in the final meeting of CCIR Study Group 4 for the 1986-1990 study period, and recent studies on implementing Integrated Services Digital Networks over satellite links.

Pan-Pacific Education and Communication Experiment by Satellite. The Pan-Pacific Education and Communication Experiment by Satellite (PEACESAT) program was founded by the University of Hawaii in 1971 and provided a satellite telecommunication network for exchange of social, environmental, health, and educational information between the countries of the Pacific Basin region using NASA's ATS-1 satellite. In 1985, fuel was exhausted and the satellite drifted away from a location useful for communications throughout the Pacific Basin.

In December NTIA was authorized to assist the University of Hawaii in the reestablishment of PEACESAT service. NTIA's responsibilities have included supporting PEACESAT activities at the University of Hawaii, providing technical consultation there and to the PEACESAT Users' Group, funding a study of PEACESAT satellite options, and obtaining satellite capacity for use by the PEACESAT system.

NTIA activities regarding PEACESAT in 1990 focused on developing the telecommunications required to reestablish PEACESAT satellite communications. The use of NOAA's GOES-3 satellite for the period 1990-1994 was obtained. Agreement was also reached with NASA to operate the satellite from Hawaii. Low-cost user Earth terminals have been developed and tested to work with the satellite.

International Training. NESDIS increased its international training activity support in collaboration with WMO and NWS. The first in a series of regional training courses was held in April 1989 at the WMO Regional Meteorological Training Center in Barbados. This Basic Meteorological Satellite Interpretation Course was aimed at those countries where the United States has provided APT/WEFAX equipment through the Voluntary Cooperation Program.

NESDIS participated in a U.S.-WMO training course in aeronautical meteorology emphasizing satellite applications at Florida State University.

NESDIS conducted training in climate computing in the Caribbean, Europe, and Africa. This training assists in the use of the climate computing system and in the applications of climate analyses.

NESDIS continues to develop training aids which are geared to the international community (WMO members). Examples include a script-slide set on basic polar-orbiter satellite interpretation, a script-slide set entitled "Localized Winds of the World," and a workbook on satellite imagery interpretation of tropical clouds and weather systems.

Along with USGS and NASA, NOAA/NESDIS is participating in the planning of a training course as part of a United Nations-International Space Year initiative.

NESDIS presented a two-week workshop at the Taiwan Central Weather Bureau in the application of satellite data for analyzing and forecasting heavy rainfall.

NESDIS NGDC participated in two training workshops sponsored by the U.N. Institute for Training and Research held in Accra, Ghana (November 1989) and Dakar, Senegal (September 1990). The workshops covered applications of integrated databases (including satellite and ground-based data) for environmental assessment.

The 2nd International AVHRR Workshop was held in Bariloche, Argentina. The AVHRR system, acclaimed "the poor-man's satellite system," provides invaluable, affordable satellite technology to scientists and users. Ideas on low-cost methods for improving the usefulness of the system were exchanged.

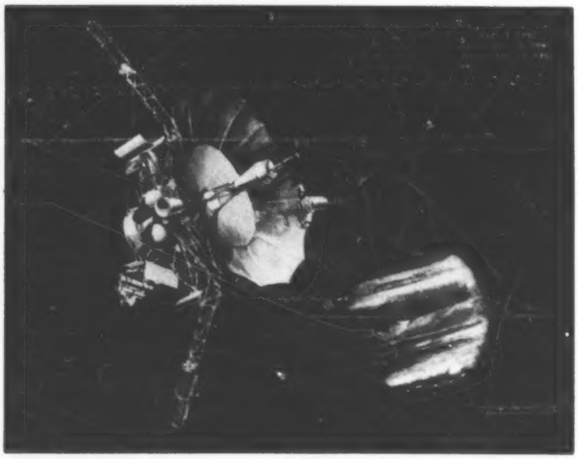
Department of Energy

The U.S. Department of Energy (DOE) provides nuclear power sources for highly specialized applications for the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD). Such power units have enabled spectacular events, such as the Voyager flyby of the planet Neptune and the Apollo scientific investigations on the lunar surface. These missions have provided us with detailed photographs and data on a variety of planetary bodies including Jupiter, Saturn, Uranus, Neptune, and their moons, and the discovery of the first extraterrestrial volcanos on the Jovian moon Io.

The majority of the power sources used on these missions have been Radioisotope Thermoelectric Generators (RTGs), capable of producing between 2 and 300 watts of electricity. However, since some planned missions will require even higher power levels, a more efficient dynamic energy conversion process has also been under development for isotopic power systems, in the 1 to 10 kilowatt range. For higher power levels, nuclear reactors are being developed and tested. Programs of this type include the SP-100 space reactor technology that is applicable over the electrical power range of tens to hundreds of kilowatts (kW). Also included is the Multimegawatt (MMW) Space Nuclear Reactor System, which can eventually extend the electrical power range to tens to hundreds of megawatts. Both SP-100 and MMW power systems can be applied to nuclear electric propulsion, but MMW systems can also be applied to nuclear thermal propulsion.

Space Nuclear Power Systems

Thus far, radioisotope power units have used thermoelectric energy converters to provide electrical power for spacecraft operations. Over time, the amount of power capable of being provided by these devices has increased from the 3 watts provided by the SNAP-3 for the TRANSIT program in 1970, to the 150 watts for NASA's Voyager program in 1976 using the multihundred watt unit, to the 285 Watt General Purpose Heat Source (GPHS) unit for NASA's Galileo (launched in October 1989), and a similar GPHS unit for the Ulysses flight successfully launched in October 1990.



Artist's concept of Galileo spacecraft to Jupiter using General Purpose Heat Source Radioisotope Thermoelectric Generators.

Nuclear reactors offer a higher power source capability for space operations purposes than is available from radioisotope power sources. One 500 watt reactor power unit, the SNAP-10A, was flown in 1965 and development was started on other units of up to about 300 kW, but was discontinued in the 1970s. In the early 1980s, because of increasing power needs of both NASA and DOD, well beyond those obtainable from radioisotopes or solar power, space reactor development was reinstated through the cooperation of NASA, DOD, and DOE. The principal space reactor program currently in development is the SP-100.

Radioisotope Thermoelectric Generators

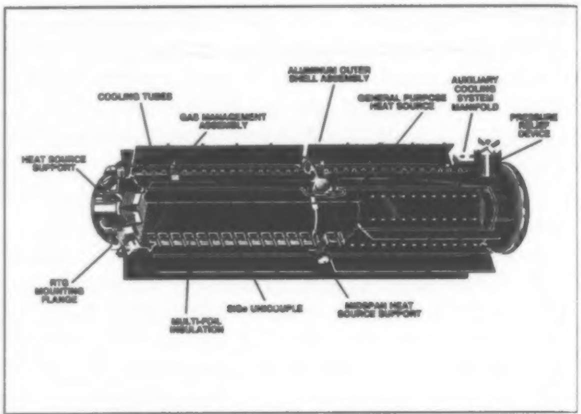
The United States has successfully used 36 Radioisotope Thermoelectic Generators (RTGs) on over 20 spacecraft launches covering a variety of different space applications. An RTG is a static device (that is, it has no moving parts) which directly converts the heat from the decay of the radioisotope Plutonium-238 (Pu-238) to electricity. Pu-238, a non-weapons material, was selected because of its relatively long half-life (about 87.6 years) and ease of containing the alpha particles (helium atoms emitted during normal decay) plus the fact that no special shielding is required for these heat sources.

Research and development has increased the conversion efficiencies of radioisotope power systems from less than 5 percent to almost 7 percent, which increases the power output or reduces the weight of the power supply, both of which are critical design factors. RTGs have demonstrated the long lifetimes, self-sufficiency, environmental independence, and operational flexibility demanded by a variety of space missions, including the capability to operate well beyond specified mission lifetimes and above design power levels. For example, the Pioneer 10 and Pioneer 11 spacecraft that were launched in March 1972 and April 1973 used RTGs to successfully power the spacecraft for their encounters with Jupiter and Saturn. In a similar demonstration, the multihundred watt RTG on the Voyager 2 spacecraft, launched in August 1977, continues to operate after its encounters with Jupiter, Saturn, Uranus, and Neptune and as it continues on into space.

A new model RTG with a more efficient fuel design, called the General Purpose Heat Source (GPHS) is the latest in a series of nuclear power sources developed for space applications by DOE. The GPHS qualification RTG unit has been operated successfully for a period of over 49,000 hours. The first two GPHS flight RTGs are providing the electrical power for the Galileo spacecraft to Jupiter launched from the Kennedy Space Center, FL on the space shuttle in October 1989. A third GPHS generator is powering the joint NASA/European Space Agency, Ulysses spacecraft to study the polar regions of the sun, which was successfully launched in October 1990. Planning has been initiated to utilize the GPHS RTG design for the Comet Rendezvous/Asteroid Flyby spacecraft and the Cassini spacecraft to Saturn, scheduled for launch in 1995 and 1996, respectively.

Significant program activities in 1989 and 1990 included issuance of the Galileo and Ulysses Final Safety Analysis Reports, launch of RTGs aboard the Galileo Spacecraft and delivery of the Ulysses RTG to the Kennedy Space Center in July 1990. In order to obtain the Office of the President's approval for launches, independent reviews and analyses of the Final Safety Analysis Reports and related safety tests were conducted by the Interagency Nuclear Safety Review Panel, made up of representatives from DOE, DOD, and NASA. After the reviews, the Panel issued Safety Evaluation Reports which were used by the Office of Science and Technology Policy in approving the launches of the nuclear powered spacecrafts.

In 1989 and 1990 the modular radioisotope thermoelectric generator program (MOD-RTG) focused on the design, development, manufacture, and test of improved multicouples in an electrically heated engineering module test unit. Over 6,000 hours of module test data have been collected. The MOD-RTG design will provide a significant advance in RTG specific power (watts/kilograms) and improved efficiency for use in NASA's lunar, Martian, and solar system exploration and DOD missions during the next decade.

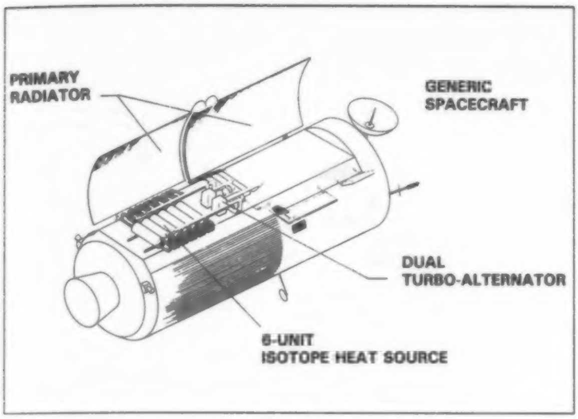


General Purpose Heat Source Radioisotope Thermoelectric Generator.

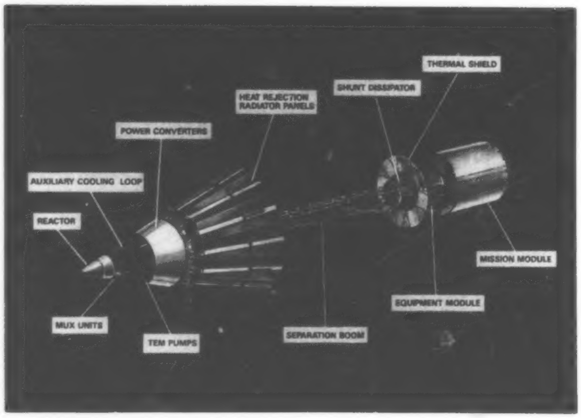
Other activities in 1989 and 1990 included the following: refurbishment of fuel production and handling facilities; selection of a contractor to design and build a new RTG shipping cask; completion of a conceptual design of a new radioisotope power system assembly and testing facility; and selection of a contractor to produce the thermoelectric converter hardware for NASA's CRAF and Cassini missions.

Dynamic Conversion/Turbine Energy Conversion System

Dynamic energy conversion systems which employ a rotating turbine/alternator conversion system (TECS) offer efficiencies approaching 18-25 percent. For higher power requirements than can be achieved by RTGs (for example, greater than 1 kW), this improved efficiency could translate into higher specific power and lower per-unit power costs, because a smaller amount of radioisotope fuel would be needed per unit of power output. Thus, the survivability, reliability, and compactness of a nuclear power system can be extended into the 1 to 10 kW range, below the power level generally considered for



Dynamic isotope power system: turbine energy conversion system (TECS) integrated with a generic spacecraft.



Artist's concept of the SP-100 space reactor.

reactor applications. The following figure shows a typical integration of a dynamic conversion system on a generic spacecraft. More likely near-term application would be for the Space Exploration Initiative. A prime TECS contractor and two subcontractors were selected in 1988. After selection of the Brayton conversion system and completion of the top-level specifications in 1988, system design work continued in 1989 with a design point established and a preliminary turbine alternator compressor design completed. In 1990, various subcomponents were tested and mission studies were conducted.

SP-100 Space Reactor Program

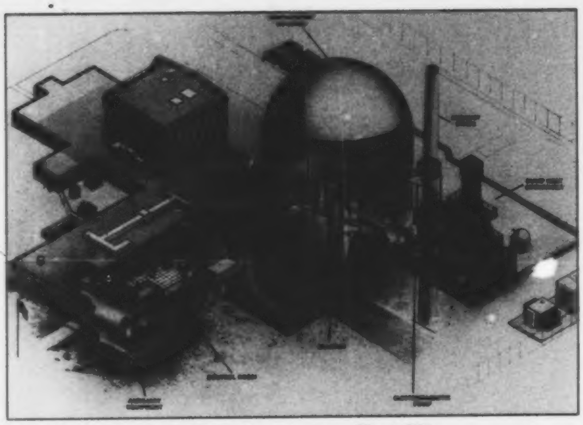
The purpose of the SP-100 program is to develop, demonstrate, and make available to NASA, DOD, and other potential users space nuclear reactor technology which can provide electric power in the range of tens to hundreds of kilowatts. This program was initiated in 1983 and is sponsored by NASA, DOD, and DOE.

The SP-100 program is in the fifth year of engineering and design of its ground test reactor, with nuclear fuel, materials, and component tests well under way. During the past two years, the program has completed major system design activities and manufactured three-quarters of the nuclear fuel for the ground test reactor. The project is presently proceeding with procurement, fabrication, testing, and demonstration of prototypic system components.

A reference space reactor design to provide 2.5 megawatts of thermal energy has been established and the preliminary design review of the ground test reactor was completed in 1989. Critical experiments to verify certain reactor functions and safety were completed. In conjunction with the reactor design effort, site facility preparation activities have taken place to allow initiation of construction modification to the existing containment facility in which the reactor will be tested. An Environmental Assessment of the test site has been completed, and a Finding of No Significant Impact was issued. A Preliminary Safety Analysis Report and an associated Safety Evaluation Report were completed in FY 1990. The accompanying figure shows the layout of the Nuclear Assembly Test site at Hanford near Richland, WA.

Los Alamos National Laboratory is producing the fuel for the SP-100 Nuclear Assembly Test. The attached picture shows work being performed in a portion of the fuel element production facilities. In the lifetime testing program, fuel and structural materials for the reactor have been exposed to simulated space reactor operating environments. Accelerated testing of SP-100 fuel samples has demonstrated the SP-100 lifetime burnup goal can be achieved. The irradiation of materials test capsules has also been completed and the initial samples are undergoing post irradiation testing.

Significant progress continues to be made in the SP-100 power converter development program. In 1989 the first SP-100 thermoelectric converter cell was fabricated



SP-100 Ground Engineering System Test Site.

Preparation for testing SP-100 fuel pins in the Fast Flux Test Facility at Hanford, WA, for the Los Alamos National Laboratory.

and it produced an increase in power density of nearly tenfold as compared to present thermoelectric technology, such as used on the recently launched RTG-powered Galileo mission. In 1990 a more prototypical thermoelectric cell was fabricated for testing in early FY 1991. Also in 1991, a fully prototypic thermoelectric cell, qualified at high temperatures, will be placed on test. Successful testing of this cell will lead to fabrication of a thermoelectric array, the configuration in which the thermoelectric cells will be used in flight. The SP-100 has transitioned from a program of primarily design and analyses to a hardware program of fabrication and test. Fabrication of the reactor vessel and internal structures has been demonstrated. Other hardware which has been placed on test includes control rod actuators, thermoelectric cells, and the thermoelectric pump magnet, to name a few.

Multimegawatt Space Reactor Program

The MMW Space Reactor program was initiated in late 1985 as a joint Strategic Defense Initiative (SDI) Organization and DOE program to meet the SDI power needs in the range of a few megawatts to hundreds of megawatts. The primary purpose of the MMW program was to establish the feasibility of at least one reactor power system concept and the associated technology which could fulfill the very high power needs of future advanced SDI applications.

The development approach for the MMW program has involved a sequential, phased narrowing down of potential concepts. In early 1988, six industrial contractors were selected to conduct Phase I system concept assessments and basic feasibility evaluations for the Phase I power systems. In mid-1989, the Phase I concepts were narrowed to three; however, for reasons given below, the program is being terminated. During FY 1990, there was no activity because the user, the Strategic Defense Initiative Organization did not provide funds and DOE did not apply its own funds without a sponsor.

During FY 1990, NASA identified various technologies developed under the MMW program as having use in the President's Space Exploration Initiative. These technologies include the use of MMW reactors to reduce trip times or to provide large amounts of power for advanced space settlements. There were no user funds in FY 1990 for propulsion or space settlements.

Thermionic Fuel Element Verification Program

The Thermionic Fuel Element (TFE) program is a component development effort which was established to resolve outstanding issues associated with the use of TFEs in continuous space reactor systems, so thermionics could be a viable technology choice for future space reactor systems. Thermionics, like thermoelectrics, is a means of converting heat directly to electricity without moving parts and offers the potential of conversion efficiencies which are higher than thermoelectric. The primary emphasis of the program is directed at demonstrating a seven- to 10-year operational lifetime of TFE components

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through accelerated and real-time testing in appropriate radiation environments.

The development effort includes a series of tests in irradiation facilities involving insulators, fueled emitters, collectors, and single cell thermionic converters. Results from the initial series of irradiation testing of these components have been encouraging and will guide the design and selection of materials for later tests in the program. The program will culminate in FY 1995 with a prototypical test of a TFE in a fast reactor environment.

Nuclear Detonation Detection

Another important DOE responsibility in the space arena is providing the specialized sensors needed to satisfy national requirements for detection, identification, location, and characterization of nuclear detonations anywhere within Earth's atmosphere or in neighboring interplanetary space. The concept of satellite-borne nuclear explosion surveillance came about during interagency discussions from 1959 to 1962 and led to the Vela Hotel (later called the Vela Satellite) Program. Six pairs of Vela satellites were launched from 1963 to 1970. The last Vela operated reliably until it was intentionally turned off in September 1984. Other newer satellite systems have since taken over this mission. From the beginning, this program has been a joint effort of DOD and DOE. Development, design, and production of the nuclear explosion detection instrumentation were responsibilities of DOE; while the rest of the satellite hardware, launch, telemetry, and day-to-day operations were responsibilities of DOD, which also had the overall coordination and scheduling role. Both DOE and DOE have shared in special operations and tests and in data interpretation and use.

The program today has three primary objectives:

- Verification of compliance with the Limited Test Ban treaty (1963) and the Nuclear Non-Proliferation Treaty (1968) wherein nuclear testing was banned in the atmosphere, under water, and in space and the non-weapons states pledged not to manufacture or otherwise acquire nuclear weapons or explosive devices.
- Provision of intelligence information on nuclear tests that occur outside the jurisdiction of the treaties or clandestinely in violation thereof.
- Detection and location of multiple atmospheric and near-Earth nuclear bursts for strategic battle management in time of war.

The information required for each of these objectives is similar and, thus, DOE has developed detector suites to simultaneously address all three.

DOE laboratories maintain continuous technology development efforts for improving the underlying technologies. The goals of these efforts include better energy resolution, faster response times, wider spectra coverage, greater reliability, and the development of advanced sensor concepts. In FYs 1989-1990 emphasis was placed on improved radiation hardening and miniaturization of the spaceborne electronic systems, on data compression logic to minimize communication channel demands, on the development of new detector concepts for the monitoring of x-rays, and on studying the effects of the space radiation environment on spacecraft systems. Many such developmental experiments are flown aboard NASA satellites and several are conducted in cooperation with the space programs of other countries.

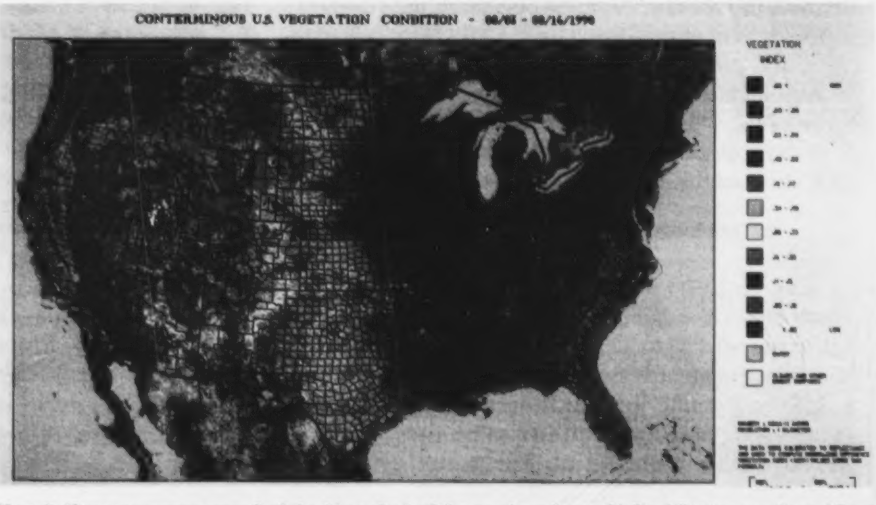
Department of the Interior

As the Nation's overseer of nationally owned public lands, the U.S. Department of the Interior's (DOI) responsibility includes the management, conservation, and development of land and water resources. To fulfill this mandate, the Department often uses remote-sensing technology. The Department supports an active program of basic and applied research in remote sensing, spatial data handling, and technique development. During 1989 and 1990, remote-sensing activities involved all nine DOI bureaus: the Bureau of Indian Affairs, the Bureau of Land Management, the Bureau of Mines, the Bureau of Reclamation, the Minerals Management Service, the National Park Service, the Office of Surface Mining Reclamation and Enforcement, the U.S. Fish and Wildlife Service, and the U.S. Geological Survey.

Remotely Sensed Data Acquisition, Processing, and Production

Satellite Data

Landsat. The U.S. Geological Survey (USGS) received, processed, and cataloged over 15,000 scenes of multispectral scanner (MSS) data and 500 scenes of thematic mapper (TM) data for the Landsat archive in fiscal years (FYs) 1989 and 1990. The U.S. Landsat archive now totals approximately 950,000 scenes. In addition, periodic updates were made to the on-line catalog system that references the U.S. archive and the nearly two million Landsat scenes held by the Landsat receiving stations in Argentina, Australia, Brazil, Canada, Italy, Japan, Spain, South Africa, and Sweden. Over 25,000 customer products resulted from the Landsat program in FYs 1989 and 1990.



Vegetation greenness map (original in color) of the conterminous United States produced from AVHRR data acquired between August 3 and 16, 1990. Maps were produced every two weeks during the 1990 growing season to show changes in the vegetation greenness due to normal vegetation growth patterns as well as other factors such as drought.

Advanced Very High Resolution Radiometer. The USGS receives and archives Advanced Very High Resolution Radiometer (AVHRR) data for the conterminous United States and portions of Canada and Mexico directly from National Oceanic and Atmospheric Administration (NOAA) satellites and processes the data for DOI land-science applications and other Federal agency research projects. The capability to receive and process tape-recorded AVHRR data of foreign areas was added in FY 1990. Approximately 30 to 40 scenes of foreign data are acquired daily and used for vegetation mapping and monitoring programs in Africa, agricultural assessment programs, and global change research.

Aircraft Data

National Aerial Photography Program. The goal of the National Aerial Photography Program is to acquire complete aerial photographic coverage of the United States (except Alaska) every five years for applications in agriculture, forestry, soils, land and resource management, mapping, and Earth science studies. Federal agency participants include the USGS (which manages the program), Bureau of Land Management, Agricultural Stabilization and Conservation Service, Soil Conser-

USGS side-looking airborne radar (SLAR) image mosaic showing Yellowstone National Park. Yellowstone Lake is at center right. The low angle of the radar beam's west-look illumination enhances terrain features. The area shown covers approximately 7,000 square miles (4,200 square kilometers) in Idaho, Montana, and Wyoming.

vation Service, National Agricultural Statistics Service, U.S. Forest Service, and Tennessee Valley Authority. Contracts were awarded in FYs 1989 and 1990 for acquisition of aerial photographs covering all or parts of Arizona, California, Connecticut, Iowa, Louisiana, Maine, Missouri, Montana, New Jersey, Nevada, Rhode Island, South Carolina, Texas, Virginia, Washington, and Wyoming. Several States that were covered also contributed funds to these contracts.

Side-Looking Airborne Radar Data. The USGS acquires side-looking airborne radar (SLAR) data to support research in energy and mineral exploration, hydrologic studies, Earth hazards investigations, and glacier and ice sheet mapping. Since 1980, these data have been acquired for more than one-third of the country. During FYs 1989 and 1990, SLAR data were acquired of approximately 90,000 square kilometers in the States of Alaska, Alabama, Arkansas, Arizona, California, Colorado, Florida, Idaho, Illinois, Indiana, Louisiana, Michigan, Missouri, Mississippi, Montana, New Mexico, Nevada, New York, Pennsylvania, Texas, Utah, and Washington. Selected data for many areas of interest are now being distributed inexpensively on compact disc-read only memory (CD-ROM).

Remote Sensing Research and Applications

Renewable Resources

Resource Inventory and Assessment. The Bureau of Indian Affairs (BIA) conducted several resource inventory and assessment projects that support the BIA Indian Integrated Resource Information Program. Landsat TM (thematic mapper) data were used to digitally classify land use and land cover on the White Earth (Minnesota) and Flathead (Washington) Indian Reservations, and riparian vegetation on the Fort Peck (Montana) Reservation. The French *Satellite pour l'Observation de la Terre* (SPOT) panchromatic and merged SPOT/Landsat TM images were visually interpreted to update existing road networks and map vegetation on the Colville (Washington) Reservation. Maps of non-irrigated croplands and surface geology were produced by visual interpretation of Landsat TM images of the Fort Peck (Montana) Reservation. Aerial photographs and SPOT and Landsat data were interpreted for rangeland assessment and prairie-dog control programs on the Fort Belknap and Crow Reservations (Montana). Historical aerial photographs were obtained for use by Indian tribes in litigation involving reservation boundaries and water-quality assessments. Results of these projects are permanently archived as part of the BIA National Data Base. Landsat TM and SPOT data were used by the BIA to develop image maps for several reservations at different scales, as determined by reservation size.

The Bureau of Land Management (BLM) used a variety of remote sensing tools for inventories and monitoring on public lands. Aerial photographs were acquired for almost 50,000 square kilometers of portions of Colorado, Idaho, New Mexico, Oklahoma, and Texas for applications involving rangeland, forest land, and wildlife management. Land-cover mapping was conducted for the Snake River Birds of Prey Area, Idaho; in Oregon for elk-habitat classification; and for a wilderness area in New Mexico and other sites in Washington and Wyoming. A new application of low-altitude aerial photographs was developed to evaluate and monitor critical riparian vegetation conditions in Colorado, Idaho, and New Mexico.

The Bureau of Reclamation (BOR) continues to use remote sensing and geographic information systems (GIS) to monitor irrigated lands to support water-rights litigation. Irrigation status (irrigated or not irrigated) was determined using Landsat TM data for all agricultural fields within the Newlands irrigation project in Nevada and combined with highly accurate field area measurements from other map sources to provide reliable estimates of the total irrigated area. Because of the success of the Newlands program, a similar database is being developed for the entire Upper Colorado River Basin.

The BOR is building a large digital geographic database of the entire Colorado River corridor in the Grand Canyon to aid in assessing environmental changes caused by Glen Canyon Dam, and to help develop future operation criteria for the dam. This database will contain 2-foot (0.6-meter) topographic contours derived using photogrammetric techniques; river morphology; land-use and land-cover data derived from current and historic aerial photographs; and other field-collected information.

The National Park Service (NPS) uses an integrated approach to remote sensing and GIS. GIS techniques are used to improve digital image classifications, while results of digital classifications are used in GIS analyses. Aircraft scanner data, Landsat MSS (multispectral scanner) and TM data, and SPOT MSS and panchromatic data are being used for all parks in Alaska and many medium to large parks in the conterminous United States. In smaller parks or where the type or level of information cannot be extracted from digital data, photointerpretation is used and the results are digitized. Satellite data are being used to develop cost-effective vegetation and land-cover information for approximately three-fourths of the National Park area.

Resource Mapping in Alaska. During the past 10 years, the USGS has worked cooperatively with Federal and State resource management agencies in Alaska to produce land-cover and terrain maps and corresponding digital databases for over 810,000 square kilometers. Land-cover databases from these projects were standardized and reformatted for twelve 1:250,000-scale USGS quadrangles by the end of FY 1990 as part of the USGS Interim Land Cover Mapping Program for Alaska.

Cooperative projects were initiated between the USGS and U.S. Fish and Wildlife Service (USFWS) to remap portions of the Arctic and Yukon Flats National Wildlife Refuges through digital analysis of Landsat TM data. Research also continued with the USFWS to evaluate SPOT MSS data for wetlands and waterfowl habitat assessment on the Central Arctic Coastal Plain. The USGS and the Alaska Department of Natural Resources successfully compared SPOT data with existing topographic maps to locate and determine the extent of erosion on the coast of the Beaufort Sea.

Wetlands Mapping and Inventory. The USFWS continues to use high-altitude aerial photographs to conduct the National Wetlands Inventory, which must be completed for the remainder of the conterminous United States by 1998 and, as soon as practicable, for Alaska and noncontiguous portions of the United States. This database is used to foster wise use of the Nation's wetlands and to expedite decisions that may affect this important resource. These data were used to update the information contained in the report "Status and Trends of Wetlands and Deepwater Habitats in the Conterminous United States, 1950's to 1970's." A current report was delivered to Congress at the end of FY 1990, and it will be updated every 10 years.

The BOR is monitoring four wetland areas in North and South Dakota by producing yearly maps of submergent and emergent wetland vegetation from large-scale aerial photographs. These maps are digitized and a GIS is used to monitor vegetation changes.

Wildfire Mapping and Monitoring. The USGS and NPS used Landsat TM data to measure the severity and extent of the fires that burned in and near Yellowstone National Park during the summer of 1988. A Landsat TM image, acquired after most fires were extinguished, was used to classify burn severity. When combined with existing NPS vegetative cover classes, the burn severity classes provide a more complete characterization of the burned area than was previously available. Tabular summaries and maps were also produced. Satellite data are also being used to monitor the effects of and recovery from fire and other natural and human impacts in Everglades, Yellowstone, Yosemite, and Mesa Verde National Parks.

The National Aeronautics and Space Administration (NASA) has funded a cooperative project among the NPS, BLM, and NOAA to determine the potential of AVHRR data for early detection of wildland fires. Computer programs to locate fires are being developed. Once this process has been refined, it will be tested using historic data about fire occurrence. If the technique is successful, options will be evaluated for operational use.

The BLM uses AVHRR data in conjunction with maps and aerial photographs for fire fuels mapping. This information is used to assess fire hazard and to assist in fire suppression once fires have been detected.

Hydrology

Accurate estimates of snow-covered areas are critical to accurate runoff estimates. The BOR and USGS are cooperating with the National Weather Service to develop new methods for snow-cover mapping using AVHRR data as part of the National Remote Sensing Hydrology Program. Techniques developed by the BOR to distinguish clouds from snow on the basis of scene brightness were refined. False signals from warm soils were eliminated, and a change detection technique was developed to distinguish snow from bright mineral surfaces and to identify snow partially obscured by conifers. Aerial photographs were acquired for comparison with snow-cover analyses made using AVHRR data acquired on the same day. USGS activities included the development of algorithms for 1) atmospheric correction of AVHRR data, and 2) adjusting for the effects of varying sun angle caused by the wide AVHRR field of view.

As part of the joint USGS/NASA/Department of Agriculture study of the snowpack in the Upper Colorado River Basin, the Ice and Climate Project continued to collect data on snowpack properties, including vertical profiles of grain size, density, and temperature at key sites across the Upper Colorado River Basin. This unique six-year data set contains the only synoptic information on both the within- and between-year variations of grain size, one of the two fundamental parameters that determine the passive microwave characteristics of a snowpack. Data concerning the other parameter, water equivalent, are obtained from the Soil Conservation Service; the combination of these two data sets is now being used to develop and verify models of the evolution of snowpack properties.

The BOR continues to develop models to predict reservoir surface temperature, turbidity, and *Chlorophyll-a* concentrations from Landsat TM and MSS images. These models reduce the amount of costly field sampling that must be done to determine the level of certain lake nutrients and are used to produce maps of lake parameters that cannot be obtained from any other source.

Oceanography

The Minerals Management Service sponsored research at Oregon State University to develop tags equipped with Argos satellite radio transmitters to monitor the migration of individual Right whales (along the Atlantic Coast) and Bowhead whales (in the Arctic Ocean). One Right whale was tagged off Nova Scotia during the 1989 summer field season and tracked for about 1,500 kilometers over a 22-day period. Additional field tests were conducted with Right whales off Nova Scotia in 1990. Information about marine mammal migration will be used to plan offshore oil-and-gas leasing, to limit the impact of oil-and-gas extraction on marine mammals.

Geology

Multispectral Data Analysis. The USGS and NASA are assessing the utility of Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) data as a geologic mapping tool in semiarid terrains. New AVIRIS data (220 bands), airborne scanner data (64 bands), and airborne MSS data (24 bands) are being evaluated to discriminate rock types and identify constituent minerals over a test site in Utah. Current research emphasizes spectral data visualization and development of procedures and products that will enhance the use of data from the High-Resolution Imaging Spectrometer and other Earth Observing System instruments to be launched in the late 1990s.

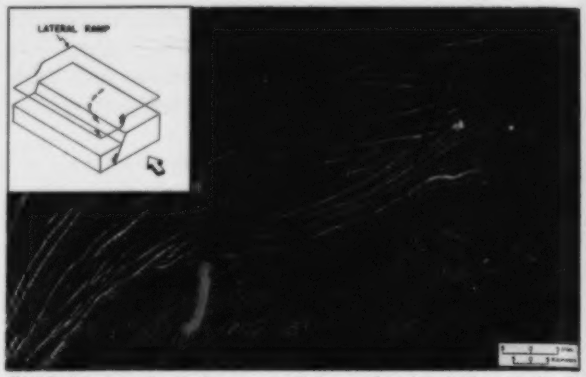
Mineral and Energy Resource Assessment. The USGS has discovered that Landsat TM data can be used to map a particular mineral that is indicative of organic material in igneous rocks. Rocks containing this indicator mineral, buddingtonite, were first observed through analysis of a Landsat TM image of the Cedar Mountains in Nevada and later confirmed by field studies and high-resolution aircraft data. Buddingtonite had been found to occur with mercury- and gold-bearing hot springs deposits in California and Nevada and may be a useful indicator for mineral exploration.

The USGS recently acquired 12 airborne geophysical and remotely sensed data sets over portions of the Osgood Mountains, Nevada, an area that includes a string of gold deposits. The data have provided much new information on geologic structures beneath the sedimentary cover, such as documenting the presence of potentially mineralized faults beyond their previously known extent, and locating a deeply buried fault that may have controlled mineralization at a newly discovered gold deposit.

USGS geologists developed a new method for mapping temperature differences in organic-rich sedimentary rocks. The method uses Landsat TM data to detect reflectance differences that are related to thermally induced chemical changes in the organic matter in the rocks. The technique was used to detect a shallowly buried mineralized pluton in Spain, where the initial work was done in a cooperative study with the Instituto Tecnologico Geominero de Espana. Information about the thermal history of sedimentary rocks is critical to energy resource studies.

SLAR images of the central and southern Appalachians have been used by the USGS to identify zones where the folded mountains become abruptly narrower, or plunge out along their trend (strike direction). These zones are believed to be areas where major flat-lying faults, deep in the subsurface, are deflected upward or downward along strike direction to form features called lateral ramps. Proprietary seismic data confirm this hypothesis. Lateral ramp zones would be poor prospects for oil and gas, but may contain mineral deposits.

The Bureau of Land Management (BLM) is using both SPOT and Landsat TM data to assess and monitor mineral development activities on public lands. Applications included mapping of coal, oil, and gas developments in the Powder River Basin (Wyoming) and monitoring of lease compliance at hardrock mineral extraction sites in California and Nevada.



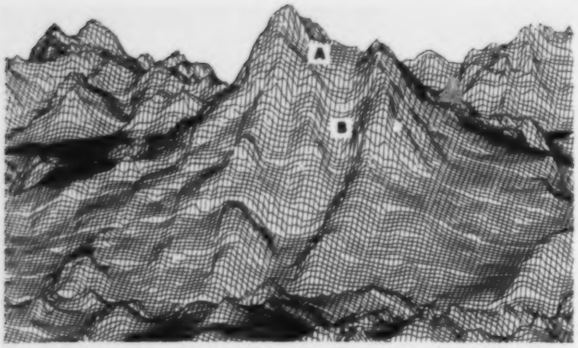
SLAR images have been used to understand the geologic structure of the Appalachian Mountains. Zones known as lateral ramps have been identified on this SLAR mosaic of Pennsylvania, shown here between the two black lines. The position of the ramp appears on the SLAR mosaic as a change in the size of the folds east and west of the ramp. The relationship of a lateral ramp to faulting in the deep crustal rocks is shown in the inset diagram. The arrow shows the direction of crustal movement.

Underground and Surface Mining Applications. Research by the Bureau of Mines (BOM) has revealed that lineament analysis could reliably identify a significant portion of unstable geologic structures in both eastern and western U.S. coal mines. During 1990 a demonstration study was initiated at a mine in northern Colorado to better define the interrelationships of lineaments with the stability of the overburden rock. Several rock-mechanics instruments were installed in the mine and on the surface to allow a direct comparison of quantitative measures of rock-mechanics parameters and stress distributions with the locations and subsurface extensions of lineaments. The results of this research will be useful for exploration, site characterization, and general mine planning.

The BOM has also integrated GIS technology with remote-sensing techniques to identify areas of underground coal mines that have potential for ground-control problems such as roof falls and water inflows. This involves combining and comparing diverse data sets such as lineaments interpreted from Landsat images, land-subsidence data, locations of past ground-control problems, geologic and topographic maps, data from in-mine, rock-mechanics instruments, and other data such as roof-control plans from a BOM engineering information system.

The Office of Surface Mining Reclamation and Enforcement (OSM) continues to use aerial photographs as part of its program with coal mining companies and State regulatory agencies in designing, monitoring, and reclaiming surface coal mines. Aerial photographs were used as the base for topographic maps to help plan mines and calculate earthwork volumes. Other design uses include evaluating the soil resources of areas to be mined and identifying the location of pre-mining drill hole sites used to map the stratigraphy of mining sites.

Aerial photographs were used by the OSM to determine regulatory compliance by identifying and



Mt. Redoubt, AK, which has been erupting periodically since December 16, 1989, is portrayed here in a digital oblique perspective view derived from 1:250,000-scale DEM data. This view, projected from a point due north of the volcano, shows both the active crater (A) which occurs in the basin between the two peaks, and the debris chute (B), down which numerous mud flows have moved. The mud flows have caused flooding in the Drift River valley which flows to the left into Cook Inlet.

monitoring areas under construction, areas to be reclaimed, wildcat-mining sites and two-acre mining sites where the mining boundaries had been exceeded, spoil ridges, and acid mine drainage. In other cases, 35-millimeter and 70-millimeter aerial photographs and videotape were used in inaccessible areas to detect large surface cracks created by underground mining and to assess the danger posed by abandoned surface mines. Pre- and post-mining aerial photographs were used in a court case to document the extent of illegal mining and to calculate the amount of coal removed by the operation.

Landslide Hazard Assessment. The USGS, NASA, and the U.S. Forest Service are developing techniques for using Landsat TM and other remotely sensed data for assessing landslide potential in California and Oregon. Initial research indicates that general vegetation classes can be used in models to predict the occurrence of debris flows, which are fast-moving, sometimes lethal landslides. Examination of forest-canopy architecture with remote sensing is a useful technique for finding the relatively slow-moving but disruptive earth flows that hamper logging operations.

Alaska Volcano Monitoring. Mt. Redoubt erupted several times during December 1989, disrupting air traffic and spreading ash over south-central Alaska. The USGS prepared a digital oblique perspective image of Mt. Redoubt from a combination of Landsat MSS data and USGS digital elevation data to support the Alaska Volcano Observatory's monitoring effort.

Planetary Studies

Archiving of Planetary Data. A large, diverse collection of planetary data is threatened with permanent loss because of its storage on deteriorating tapes and the lack of personnel who have special knowledge of the original data. The USGS is cooperating with the Jet Propulsion Laboratory to record these data onto CD-ROMs for long-term protection. Processing is complete for Voyager images taken during the Neptune and Uranus encounters, and the best of the Saturn and Jupiter encounters. The entire Viking Orbiter data set, consisting of over 50,000 radiometrically corrected images of Mars, is being transferred. The USGS is also advising on the procedures to archive the huge data sets from the new missions such as Galileo, Mars Observer, and Magellan.

Mars Digital Cartographic Database. The USGS has completed a global mosaic of Mars using nearly 5,000 individual Viking Orbiter images. It is the largest known digital-image mapping project undertaken by any agency, providing the first complete view of Mars at relatively high resolution (231 meters per mosaic pixel).

Voyager Flyby of Neptune's Moon Triton. Images of Triton's complex surface became the highlight of the Voyager Neptune encounter, revealing a dense concentration of pits crisscrossed by ridges, caldera-like structures possibly containing frozen lakes, and at least two active geyser-like plumes. Computer processing techniques were developed to produce high-resolution, geometrically controlled mosaics from 50 individual digital multispectral images in fewer than three days; in the past, months or years have been required to produce such high-quality mosaics.

Earth-Approaching Asteroids. Observers around the world, including USGS scientists, continue to discover new Earth-approaching asteroids. Five such asteroids were found in a single dark-of-the-moon observing period in late 1989, and USGS scientists independently discovered three more asteroids and confirmed the existence of an another one in early 1990. There are estimated to be about 1,000 Earth-approaching asteroids larger than one kilometer in diameter. Asteroids or comets that can be detected early are of a size that is expected to modify the global climate of Earth for at least a short time. After an impact, another one might not be expected to occur for 100,000 years.

Cartography

Satellite Image Mapping. The USGS continued to produce image maps from satellite data. Noteworthy examples include: 1:250,000-scale Landsat TM image maps of the San Francisco Bay area, California, with selected type printed in opaque silver ink on the image side to provide unobtrusive presentation of feature names; a black-and-white 1:250,000-scale Landsat band 7 image map of the Great Salt Lake area showing the Newfoundland Evaporation Basin, which was created by pumping water from the Lake to reduce flooding during a period of unusually high runoff from surrounding mountains; and a 1:7,500,000-scale false-color image map of the conterminous United States produced from AVHRR data.

The BLM continued its image mapping work by applying techniques for combining image data sets with different spatial and spectral characteristics. Landsat TM data and SPOT data were combined digitally to produce an image that has the spectral quality of the Landsat TM multispectral data and the 10-meter resolution of the SPOT panchromatic data. More than 250 7.5-minute-equivalent map quadrangles were produced using these procedures.

Global Positioning System. Global Positioning System technology now provides most of the positioning required for mapping control, revision, and accuracy testing within DOI. New systems capable of two-meter positional accuracy have enhanced production. The USGS completed two major surveys in California to support land-subsidence studies and is also using this technology for ground-water well locations and for stream-gauging site locations. USGS is using Global Positioning Systems in the analysis of the Loma Prieta (California) earthquake. Prior to the earthquake, USGS geophysicists had identified this area as a potential earthquake zone and had established a network in the area to monitor movement. Remeasurements of the network commenced two days after the earthquake and will be extremely useful for post-seismic studies.

This computer-generated perspective view of one of the caldera-like depressions on Neptune's moon, Triton, was produced from a high-resolution Voyager image. The caldera floor, approximately 200 kilometers in diameter, is extremely flat and probably was formed by the volcanic eruption of ice lavas of very low viscosity. The topography was vertically exaggerated 20 times to produce this perspective view.

Global Change Research

Global Ice Monitoring. Landsat and AVHRR images acquired during the past 18 years have been used by USGS glaciologists to measure changes along the coastal margin of the Antarctic ice sheet. During 1989 and 1990, velocity measurements were made of 20 outlet glaciers or ice streams from sequential paired Landsat images. Determination of the mass balance of the Antarctic ice sheet, which contains 91 percent of Earth's glacier ice, is important in ascertaining whether the ice sheet is gaining or losing mass. Even a slight change in the volume of ice in Antarctica would result in a rise or fall of sea level. Changes in the Antarctic coast are being mapped under a five-year cooperative program involving the USGS, NASA, the United Kingdom, Norway, and the Soviet Union. More than 300 new Landsat images and Soviet

Soyuzkarta photographs are being compared with earlier Landsat images of Antarctica, acquired between 1972 and 1977.

In 1978, the USGS began to prepare a "Satellite Image Atlas of Glaciers of the World," a long-term project involving more than 55 scientists from the United States and 29 other countries to study the glaciated regions of Earth from Landsat MSS images and ancillary data. The distribution of glaciers in each geographic area is compared, wherever possible, with historical information about their past extent. The second of 11 planned chapters, covering the glaciers of Irian Jaya, Indonesia, and New Zealand, was published in 1989.

Ice and Climate Project. The USGS actively participates in the international Ice and Climate Project. The goal of the project is to understand the variations of the cryosphere—sea ice, snow, ice sheets, and glaciers—in the global hydrologic cycle. These variations strongly affect the world's water resources through the complex interactions between the cryosphere, the atmosphere, and the ocean at time scales that range from days to decades and longer. Project investigators are performing pre-launch experiments, developing algorithms, and organizing post-launch experiments for the first European Research Satellite (ERS-1) of the European Space Agency and the Franco-American Topex-Poseidon Satellite (TOPEX). As part of an ERS-1 pre-launch experiment, a Seasonal Ice Zone Experiment (SIZEX) expedition was conducted in 1989 to study the complicated atmosphere-ice-ocean interactions in the Barents and Greenland seas. Polar and subpolar water and air masses in this region exchange heat, water vapor, and momentum, which strongly influences global weather and climate.

Micromorphology of Coastal Areas. Rising sea level, severe storms, and coastal engineering projects cause changes in low-relief coastal features such as spits, barrier islands, wetlands, and deltas. However, existing maps of U.S. coastal areas do not have sufficient topographic contours to accurately delineate these areas. To obtain more detailed coastal information, the USGS initiated a cooperative research project with the NASA Goddard Space Flight Center and the Coastal Research Center of Woods Hole Oceanographic Institution to use airborne laser altimeter data to measure the micromorphology of coastal features on outer Cape Cod, MA. Several airborne laser altimeter profiles, with vertical elevation and horizontal position accuracies of less than one meter, were acquired over portions of the Cape. Preliminary results indicate that these data will permit contour intervals of 1 meter to be delineated, providing an important new capability to rapidly and accurately determine changes in low-relief areas.

Earth Observing System. The USGS is cooperating with NASA to use the USGS EROS Data Center for processing, archiving, and distribution of land-related data from the Earth Observing System (EOS) polar-orbiting platforms beginning in the late 1990s. During 1989 and 1990, USGS participated with NASA in the conceptual design of the EOS Data and Information System (EOSDIS). The USGS is working with NASA and other elements of EOSDIS to develop capabilities to process, archive, and distribute EOS precursor data sets in preparation for development of the operational system.

Global Land Information System. The USGS is developing the Global Land Information System, an on-line land data directory, catalog, and inventory system, to provide an interactive source for information about, and access to, data pertaining to Earth's land surface. It will provide an on-line, interactive, geographic- and discipline-oriented data query and product-request capabilities. The system will serve as one of the principal nodes of the national Global Change Data and Information System being developed by the Interagency Working Group on Data Management for Global Change. As a demonstration of information system interoperability, directory interchange format records describing data holdings of the Global Land Information System have been submitted to the Global Change Master Directory. In addition, an interim network link between the Global Change Master Directory and the USGS EROS Data Center allows Master Directory users to place requests electronically for additional information or to search the inventory of a particular data set.

Prototype Land Data Sets. The USGS has begun a major initiative to organize, produce, and distribute land data sets consisting of satellite image data integrated with other related land data. These data sets will enable global-change scientists to quantify fundamental land-surface attributes needed to model land-surface processes, detect and monitor land-surface change, and map land cover for regional, continental, and global-land areas. Major areas of activity are associated with 1) developing the logistics for acquiring satellite image data of Earth's land area; 2) developing consistent, standardized processing procedures; 3) developing or refining related land data to provide an improved base of land-surface data for integrated evaluation with satellite data; and 4) integrating satellite data with other land data for distribution to the global-change science community. Periodic data sets of the conterminous United States are being produced from AVHRR data to provide biweekly calibrated and registered spectral data and a vegetation-greenness index at one-kilometer resolution. Additional derivative data sets, such as biweekly albedo and vegetation greenness change maps, will be published annually on CD-ROM.

The BOR is working with the USGS and Utah State University to produce maps of agricultural crops and natural vegetation for five river basins in California, Colorado, Nevada, and Utah using Landsat TM and MSS data. These maps, as well as other data such as soils, elevation, slope angle, and slope aspect, are put into hydrologic and water-use models that provide estimates of the effects of various climate change scenarios on water quality, availability, and use.

International Activities

Africa

The USGS provides technical and logistical support to the U.S. Agency for International Development (USAID)-sponsored Agricultural-Hydrological-Meteorological (AGRHYMET) program in West Africa. This program, established in the 1970s, is designed to provide timely meteorologic and hydrologic data to decisionmakers in nine West African countries and the World Meteorological Organization for their use in agricultural forecasting. The program has facilities at an AGRHYMET Regional Center in Niamey, Niger, and at National AGRHYMET Centers in each of the member countries (Burkina Faso, Cape Verde, Chad, Guinea Bisseau, Mali, Mauritania, Niger, Senegal, and The Gambia). USGS staff are transferring USGS remote-sensing and GIS technologies to African specialists at the Regional and National Centers. The Regional Center now receives, processes, and distributes AVHRR satellite data and produces vegetation condition maps for the nine member nations.

With USAID support, the USGS continued to assist African countries in producing and using AVHRR-based vegetation condition maps for locust control and vegetation monitoring in Africa. The USGS successfully transferred this technology to the AGRHYMET Regional Center in Niamey, Niger; the Center provided the products directly to AGRHYMET countries during the 1990 season, and similar products were provided to Sudan and Morocco. Although the locust situation has improved dramatically since 1988, the maps provide important information during years of low locust populations as well as in plague years.

The USGS also continued to provide technical assistance to the USAID Famine Early Warning System project which was established in 1985 by USAID to identify human populations at risk of food shortages and famine in seven Sahelian countries. The project uses GIS technology and AVHRR satellite data to target and monitor areas with famine risk. The USGS also assisted in the development of data-handling procedures and maintains the Famine Early Warning System data archive.

Middle East

The USGS continued its support of remote-sensing activities in the Middle East. The USGS supported the Saudi Arabia Directorate General for Mineral Resources Remote Sensing facility in mineral-resource and general geologic mapping studies. Landsat image maps at scales of 1:20,000, 1:50,000, and 1:250,000 were produced for the Abu Dhabi Emirate, United Arab Emirates, to support ground-water studies and general geologic mapping.

At the request of the Yemen Government and USAID, the USGS provides assistance in the application of airborne and satellite remotely sensed data to mineral-resource assessments in North Yemen. The Government of Jordan received assistance from the USGS, through USAID, in the use of remotely sensed data to support general geologic mapping of the entire country. The USGS also provided technical assistance to the Government of Qatar's National Remote Sensing Center.

Latin America

Under the auspices of the Pan American Institute of Geography and History and the DMA Inter-American Geodetic Survey, and in cooperation with the Instituto Geografico Militar of Bolivia, the USGS conducted an evaluation of SPOT and Landsat TM data in 1989 for change detection and map revision of the Santa Cruz de la Sierra (Bolivia) 1:50,000-scale map. This project successfully demonstrated the use of satellite images with sufficient spatial and spectral resolution and positional accuracy for map revision at 1:50,000 scale.

Since 1988, the BOR has provided consultation to the Brazilian Ministry of Irrigation on the use of land remote sensing and GIS technology to compile basic environmental information for planning irrigation development in the semiarid, northeast region of Brazil.

Iceland

The USGS continued cooperation with the NASA Goddard Space Flight Center and the National Research Council of Iceland in a study of active volcanic zones and glaciers of Iceland using SLAR and airborne laser altimeter data. A Global Positioning System survey facilitated precise plotting (with an error of less than one meter) on base maps of numerous airborne laser altimeter profiles of lava flows, erosional changes on the island of Surtsey, and heavily crevassed surfaces of several outlet glaciers from the Vatnajokull ice cap in Iceland.

Antarctica

The USGS, NOAA, and the Royal Aircraft Establishment Remote Sensing Center (United Kingdom) are compiling a 1:5,000,000-scale image mosaic map of Antarctica from AVHRR satellite images. It will be the first image map ever published of the entire continent. Because the ice-bound coast of Antarctica is dynamic, conventional mapping techniques are unsuitable for rapidly mapping the entire continent.

The USGS has completed collection of data for the National Science Foundation-funded study on the ice streams of West Antarctica, using low-frequency, short-pulse, ice-penetrating radar, and is now analyzing the data. Significant variations in the bottom return of the radar signal tentatively appear to be related to the dynamics of the ice streams. These studies suggest that the West Antarctica ice sheet may behave abnormally, which may be relevant to global-change studies.

Department of Agriculture

Space-related activities of the U.S. Department of Agriculture (USDA) have in the past primarily focused on satellite remote sensing. The research utilizes remotely sensed data from space platforms in the assessment of agricultural conditions and in management of water, soil, and forest resources. In 1989 and 1990 effects were expanded to include basic research on the development of plant-growing systems that could be adapted to manned space vehicles. Plant scientists at USDA's Beltsville Agricultural Research Center in Beltsville, MD are now engaged in research on plant-growth characteristics in controlled environments. The primary objective of the research is to find optimum growing conditions for particular plants given certain environmental stress factors. The research has a direct bearing on growth and productivity of plants that might be grown in the closed environment of a spacecraft.

Recent results in remote sensing research, using Landsat multispectral scanner (MSS) and thematic mapper (TM) data, have demonstrated that digital Landsat data can be used to monitor suspended sediments—such as soil particles, sand, and organic matter—in lakes and reservoirs. Suspended sediments are the major cause of degradation of surface water quality.

A two-year investigation by USDA's Agricultural Research Service (ARS) on the utility of remotely sensed data to monitor suspended sediments in selected lakes in Oklahoma was completed in 1989. The cooperative project involving the Oklahoma Conservation Commission and the ARS Water Quality and Watershed Research Laboratory based in Durant, OK has produced technology which can economically assess in detail the suspended sediment in Oklahoma reservoirs on a repetitive basis. The effort is now being expanded to a State-wide assessment of over 100 lakes in cooperation with the Oklahoma Water Resources Board and another 60 lakes in cooperation with the Oklahoma Conservation Commission. A unique feature of the initial research activity was the use of a corps of volunteer observers who visited and collected data from 16 small- to medium-sized lakes in south-central Oklahoma each day of a Landsat overpass.

The suspended sediments in lakes and reservoirs are derived from upland soil loss. This upland soil loss is caused by sheet, rill, and gully erosion and has been recognized as a significant cause of topographic change on the landscape. Currently, changes in landscape topography and soil loss from gullies are estimated using field measurements which are costly and time consuming, yet do not accurately map the surface topography in the detail necessary to provide good estimates of soil loss. Research at the USDA ARS Hydrology Laboratory, Beltsville, MD is under way to evaluate the use of remote-sensing technology to measure upland soil erosion and the subsequent suspended sediments in water bodies.

Close-up of tomato plant growing in a plant culture system designed for NASA. Two plastic pipes are fitted one inside the other. The inner pipe is wettable and porous. It serves as the source from which the roots draw nutrients and also helps support the roots. (USDA, Agricultural Research Service photo)

An airborne laser profiler is being used to monitor soil surface topography. Airborne laser-profile data collected over simulated gullies and natural conditions clearly showed the location, depth, and cross section of simulated gullies as small as 20 to 70 centimeters wide and 10 to 30 centimeters deep and demonstrated the potential for using this technology to monitor changes in surface

Tomatoes growing in a plant culture system designed for NASA. Unlike hydroponic systems on Earth, plants in space systems will be unable to absorb water or nutrients in the form of water droplets. In weightlessness or very small simulated gravity from centrifugal force, the liquid will have to be absorbed as a thin film to keep it from floating away. (USDA, Agricultural Research Service photo)

topography to provide better estimates of soil loss from uplands and thus better estimates of the potential impact of suspended sediments on water quality.

Using these two remote-sensing techniques, Landsat MSS and TM, and the laser profiler can provide conservation agencies with better information on upland soil loss and suspended sediments in inland water. Improved information will allow conservation agencies to make better plans for controlling soil loss and improving water quality.

The University of Texas at Austin and the ARS Remote Sensing Research Unit at Weslaco, TX have begun a cooperative program with support from the local cotton industry to evaluate agricultural applications of Landsat multispectral satellite imagery in the Rio Grande Valley. The primary application studied was that of monitoring the destruction of defoliated cotton stalks for pink bollworm control. Initial research indicated that other useful agricultural management applications would be possible, including mapping of saline soil and cotton root rot occurrence. Preliminary results indicate that Landsat 20-meter-resolution, TM multispectral satellite imagery is sufficient for on-farm management decisions about individual fields.

Research was begun in 1989 to integrate satellite remote-sensing data into forage-production modeling. The project is a cooperative effort of the ARS Crops Research Laboratory, Fort Collins, CO and the Earth Resources Observation Systems (EROS) Data Center, U.S. Geological Survey, Sioux Falls, SD. The primary goal of the investigation is to develop procedures for monitoring primary production in grassland ecosystems. A significant aspect of the new research is the use of low-resolution multispectral data from U.S. polar-orbiting weather satellites as a primary data source. Data from the advanced very high resolution radiometer (AVHRR) sensor are being compared with data derived on-site at an experimental range in northeastern Colorado. The AVHRR data are converted to "vegetation index numbers" through mathematical combinations of two channels (spectral bands) on the sensor. The vegetative index numbers indicate the presence and amount of green vegetation. Successful development of procedures to monitor large grassland areas using AVHRR-derived parameters will overcome, in part, the disadvantages of the low-resolution sensor and will permit full and advantageous use of the system's other primary characteristics: coverage of large areas of Earth's surface and frequent repeat coverage.

Scientists from 20 countries presented their research at USDA's 15th annual science symposium, "Remote Sensing for Agriculture," held in May 1990. The symposium, co-sponsored by the Department's Agricultural Research Service and NASA's Goddard Space Flight Center, examined how some of the newest space technology can help agriculture and the environment. Much of the research presented was aimed at interpreting measurements of spectral radiation—light, heat, and microwaves reflected or emitted from soil, water, and plants. As techniques for comparing spectral measurements made from sensors on aircraft and satellites improve, remote

Scientists of USDA's Agricultural Research Service demonstrate applications of airborne video systems at the Department's 15th annual science symposium, "Remote Sensing for Agriculture." Videotaping farms, ranches, and forests from aircraft could provide fine detail and immediate, cost-effective information for monitoring and management. (USDA, Agricultural Research Service photo)

Root growth of six-day-old soybean plants is monitored to determine the response to different wavelengths of light. More growth goes into the leaves when plants are exposed to light without its blue component. (USDA, Agricultural Research Service photo)

sensing will be increasingly used to monitor crop and forage growth over large areas of Earth's surface.

The "spinoff" from space research and development to agriculture, for example, the use of satellite data and imagery to monitor vegetation conditions, has been well-publicized. What is less well-known, except in portrayal of futuristic scenarios, is the reverse flow, from agricultural research to space systems development.

As the prospect for extended habitation of space draws nearer, there will be increased need to be able to develop a controlled ecological life support system (CELSS), in which higher plants (or perhaps algae) are used as a means of providing food, regenerating the atmosphere, and recycling human wastes.

Through its extramural programs at a number of universities and through its intramural programs at the Kennedy Space Center in Florida, the Ames Research Center in California, and the Johnson Space Center in Texas, NASA is taking the essential steps required to have a functional CELSS in space.

During the past two years, scientists at the Beltsville Agricultural Research Center have been working with NASA scientists to identify radiation requirements for growing plants in space and to develop special systems for growing tomato plants in solution culture on a tabular membrane system. The studies are part of an ARS research program in the Climate Stress Laboratory to determine the physiological and morphological effects of root restriction. Guidance on radiation requirements is being provided by ARS scientists in the Plant Photobiology Laboratory.

Although USDA scientists have provided informal advice to NASA in their CELSS program since the mid-1970s, this is the first effort by ARS investigators to develop a cooperative laboratory research program with NASA on CELSS. Although there are many questions which must be answered before astronauts can begin to harvest crops in space, this example of technology transfer on the part of USDA opens up an exciting avenue for continued close cooperation between the two Federal agencies.

Federal Communications Commission

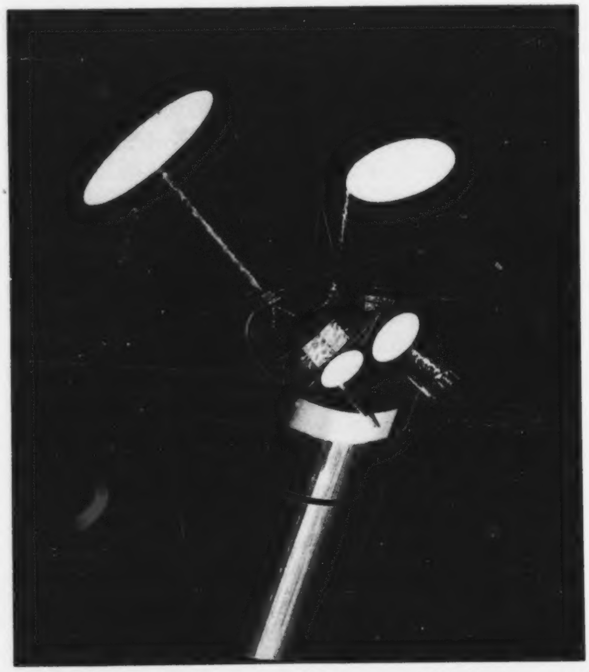
Communications Satellites

International Commercial Communications Satellites

At the beginning of 1989, the International Telecommunications Satellite Organization (INTELSAT) global communications system consisted of 13 operating satellites in geostationary orbit: one INTELSAT IV-A, three INTELSAT Vs, one INTELSAT V-M, two INTELSAT V-As and one INTELSAT V-B in the Atlantic Ocean Region (AOR); two INTELSAT V-Ms and one INTELSAT V-A in the Indian Ocean Region (IOR); and one INTELSAT V and one INTELSAT V-M in the Pacific Ocean Region (POR). The last INTELSAT IV-A series satellite was retired in August 1989.

The final INTELSAT V series satellite, the INTELSAT V-B (F-15), was launched on January 26, 1989, by an Ariane 2 rocket and placed in orbit at 60 degrees East Longitude in the IOR. The first INTELSAT VI series satellite, the INTELSAT VI (F-2), was launched successfully on October 27, 1989, by an Ariane 44L launch vehicle, and was placed in orbit at 335.5 degrees East Longitude in the AOR. The second INTELSAT VI series satellite, the INTELSAT VI (F-3), was launched on a Martin Marietta Titan 3 launch vehicle on March 14, 1990. Because the second stage failed to separate from the payload, the satellite did not achieve geosynchronous orbit and is presently stranded in a low-Earth orbit some 300 miles high. In an effort to rescue the satellite, INTELSAT has contracted with NASA for a shared shuttle mission in early 1992. The third INTELSAT VI series satellite, the INTELSAT VI (F-4) was launched on a Titan 3 on June 23, 1990. Upon completion of in-orbit testing, the satellite will enter service at the 332.5 degree East Longitude orbital location in the AOR. As of September 30, 1990, INTELSAT deployed or had plans to deploy a total of 15 satellites in geosynchronous orbit: two Vs, one V-M, one V-A, one V-B, and two VIs in the AOR; two V-Ms, one V-A, and one V-B in the IOR; and two Vs, one V-M, and one V-A in the POR.

The United States and the United Kingdom completed Article XIV(d) consultation with INTELSAT for two Ku-band satellites to be used by the Orion Satellite Corporation for service between the United States and the United Kingdom. The Commission is now considering Orion's request for final authority to construct, launch, and operate the satellites.



Artist's rendition of INTELSAT VI, first one of series launched October 27, 1989.

Domestic Commercial Communications Satellites

In 1989 and 1990, domestic fixed-satellite licensees continued to implement satellite systems that were authorized in 1988. These satellites will provide domestic satellite capacity through the 1990s and will offer users a wide range of services including video services, high-speed data services, private network services, and audio services.

Although no new satellites have been launched since the beginning of 1989, 42 satellites are currently authorized for operation. As of September 30, 1990, 30 domestic fixed-satellites were in-orbit and located between 69 degrees West Longitude and 143 degrees West Longitude on the geostationary orbital arc.

Maritime Satellite Service

Efforts to establish a Global Maritime Distress and Safety System are continuing. The International Maritime

Organization is developing the system which will use INMARSAT A, INMARSAT B, INMARSAT C, and INMARSAT M ship Earth stations via the International Maritime Satellite Organization (INMARSAT) satellite system. On two other satellite systems, emergency position indicating radio beacons (satellite EPIRBs) are providing initial distress alerting information from ships to rescue coordination centers. The systems are the polar-orbiting SARSAT, a NOAA Weather Service satellite for search-and-rescue satellite data tracking, and the Russian equivalent, called COSPAS. The INMARSAT Council, in mid-1990, approved L-band EPIRBs through the INMARSAT satellites at geostationary orbit. The Global Maritime Distress and Safety System is planned to be phased in between 1992 and 1999.

INMARSAT serves over 10,000 vessels through its 59 member-country organization. Twenty coast stations in 15 countries are in operation, with several more planned. Currently, INMARSAT is leasing the following groups of satellites. These include two in-orbit satellites from the European Space Agency—an operational MARECS A in the Pacific Ocean Region (POR) and an operational MARECS B-2 in the Atlantic Ocean Region (AOR); three in-orbit INTELSAT Maritime Communications Subsystem (MCS) satellite packages—the operational MCS B (F-6) in the AOR, the operational MCS D (F-8) in the POR, and the operational MCS A (F-5) in the Indian Ocean Region (IOR); and three MARISAT back-up spare satellites leased from Comsat General—the MARISAT F-1 in the AOR, the MARISAT F-3 in the POR, and the MARISAT F-2 in the IOR which are also for special-purpose use. In the fall of 1990, INMARSAT introduced operation in a "Fourth Ocean Region," the Atlantic Ocean Region—West (AOR-W), by relocating the MARECS B-2 further west, thereby enabling INMARSAT to provide improved global coverage.

The first INMARSAT second-generation satellite is projected to become operational in late 1990. The second-generation satellite's capacity will about triple that of the present leased satellites. In 1989, INMARSAT issued a Request for Proposals for a third-generation satellite system. The specifications for this system include spot beams and the capability to operate within the full maritime spectrum. In mid-1990, the INMARSAT Council authorized the Director General to negotiate and award a contract to GE Astro by the end of 1990 for the purchase of three or four INMARSAT satellites, pending the successful negotiation of outstanding technical, managerial, legal/contractual, and financial issues.

Aeronautical Satellite Service

In 1989, the Federal Communications Commission decided that the public interest requires that INMARSAT international aeronautical mobile satellite services be made available to users in the United States and that these services are best suited for aircraft that are in international flight. The Commission also concluded that the best means of both promoting competition in the provision of INMARSAT aeronautical services and achieving timely and effective U.S. entry into the world market would be to permit Comsat to be the U.S. provider of INMARSAT aeronautical space segment capacity as ancillary to its role as U.S. Signatory and operating entity for INMARSAT maritime services.

The process of adopting amendments to the INMARSAT Convention and Operating Agreement, which will allow it to offer aeronautical services on a competitive basis, was completed in 1989 and the amendments are in effect. INMARSAT's four second-generation spacecraft are being constructed with 3 megahertz (MHz) of bi-directional bandwidth in the Aeronautical Mobile-Satellite Service (R) band. The third generation satellites are proposed to be capable of operating over the entire Aeronautical Mobile-Satellite Service (R) allocation of 10 MHz of bi-directional bandwidth.

The International Civil Aviation Organization through its subcommittee on Future Air Navigation Systems and the Aeronautical Mobile Satellite Service Panel have been discussing standards for aeronautical satellite services and other issues involving the use of satellites in a coordinated program for civil aviation. The aviation community is actively developing, through the Airlines Electronic Engineering Committee, aircraft equipment standards for satellite voice-and-data services. The aviation industry, in cooperation with INMARSAT, is developing aircraft antennas and avionics needed for this service. Aeronautical Radio, Inc., has requested to provide international aeronautical services via INMARSAT by interconnecting its terrestrial VHF (very high-frequency) network with satellite facilities for oceanic coverage. In addition, the

American Mobile Satellite Corporation is proposing to provide exclusive U.S. domestic aeronautical mobile-satellite service on its system (see following section).

In September 1990, the United States formally accepted amendments to the INMARSAT Convention and Operating Agreement which will enable INMARSAT to provide land mobile-satellite services on a competitive basis. These amendments are similar to earlier amendments which enabled INMARSAT to provide aeronautical services. The land mobile amendments will enter into force upon acceptance by two-thirds of INMARSAT's member countries representing two-thirds of the investment shares. With U. S. acceptance, the investment share requirement of two-thirds was met; however, acceptance by 22 additional member countries was still needed. In anticipation of approval, the third-generation INMARSAT satellites are proposed to be capable of operating over the entire land mobile-satellite allocation of 7 MHz of bi-directional bandwidth.

Mobile Satellite Services

The radiodetermination satellite service (RDSS) continued to develop in 1989. This service was authorized in 1986 and allows subscribers to determine latitude, longitude, and altitude, and to exchange brief coded messages using hand-held or vehicle-mounted transceivers. Geostar Positioning Corporation, the licensee in this service, continued construction of its three dedicated RDSS satellites, which are to operate in the frequency bands allocated for RDSS. Geostar also commenced two-way start-up service in 1989 by using capacity on domestic fixed satellites on a non-interference basis.

In addition, the Commission in 1989 authorized the American Mobile Satellite Corporation to construct, launch, and operate three satellites in the mobile satellite service (MSS). The satellite network, which is expected to be implemented in 1993 and 1994, will provide a variety of domestic land, aeronautical, and maritime mobile satellite services. The mobile telephone, radio, and data services proposed for the system will be used for long-range vehicle dispatch and location services, emergency communications, rural telephone service, and paging service. Aeronautical voice-and-data communications are planned for both safety and commercial purposes, such as air traffic control and airline passenger communications. Issuing the MSS license culminated a proceeding in which the Commission proposed to allocate spectrum for MSS in 1985, allocated 27 MHz of L-band spectrum in 1986, and established licensing procedures in 1987.

In 1989, the Commission also authorized Qualcomm Corporation to construct and operate a two-way mobile data communications network that uses capacity on domestic fixed satellites. Although Qualcomm's proposed satellite-to-mobile-unit transmission link was to operate in frequency bands that were not allocated to the mobile satellite service, the Commission permitted Qualcomm to provide these services on a non-interference basis to other authorized services in those bands. Qualcomm's network is designed to provide a variety of data services between a customer's operation center and its mobile users.

Finally, in response to several applications that were filed, the Commission initiated proceedings to consider establishing new mobile-satellite services in new frequency bands. In 1990, the Commission adopted a Notice of Inquiry asking for information that will assist it in developing technical standards and regulatory policies for the possible introduction of a satellite sound-broadcasting service. In addition, the Commission issued a Notice of Proposed Rulemaking to reallocate frequencies in the lower portion of the L-band to a generic mobile-satellite service (that is, to land, aeronautical, and maritime mobile-satellite communications).

Direct Broadcast Satellite Service

The Commission authorized the Direct Broadcast Satellite (DBS) service in July 1982, in order to provide satellite delivery of video programming directly to homes via small (two 3-foot-diameter), relatively inexpensive ($300-$500), receiving stations. The Commission granted the first several conditional construction permits later that year. Two of those original permittees continue to hold their permits and are currently scheduled to begin operations by late 1992. U.S. Satellite Broadcasting Company, Inc., and Dominion Video Satellite, Inc., are each authorized to provide eight channels of service to each half of the United States.

Several additional parties have subsequently received conditional construction permits and should begin operations in three to four years. Hughes Communications Galaxy, Inc., and Advanced Communications Corporation received conditional construction permits several years ago and are each authorized to provide 27 channels of service to each half of the United States. In February 1990, formation of "Sky Cable," a partnership consisting of Hughes, Cablevision Systems Corporation, NBC, and The News Corporation Limited, was announced. Sky Cable projects launch of its service in late 1993.

Continental Satellite Corporation, Direct Broadcast Satellite Corporation, DIRECTSAT Corporation, and EchoStar Satellite Corporation have each been authorized to begin satellite construction to provide 11 channels of service to each half of the United States. All conditional permittees have recently submitted contracts which claim to demonstrate due diligence in satellite construction.

Most of these parties would prefer to operate with single signals covering the entire United States, rather than with pairs of signals, each covering half of the country. The Commission has approved such operations, although it also instituted a rulemaking proceeding to determine whether and how to ensure DBS service to Alaska and Hawaii in light of such single-signal operations. Commission action on this matter can be expected in the near future.

International Conference Activities

During 1989, the Commission adopted a Notice of Inquiry initiating the private sector preparations for the 1992 International Telecommunication Union World Administrative Radio's "Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum." The agenda for this conference has been finalized. The main objective of the conference is to provide allocations for radio services including space services which were not satisfied at previous radio conferences and to accommodate low-Earth-orbit satellite systems. The Commission also established a U.S. Government/private sector Advisory Committee to provide recommendations for positions and proposals for this conference.

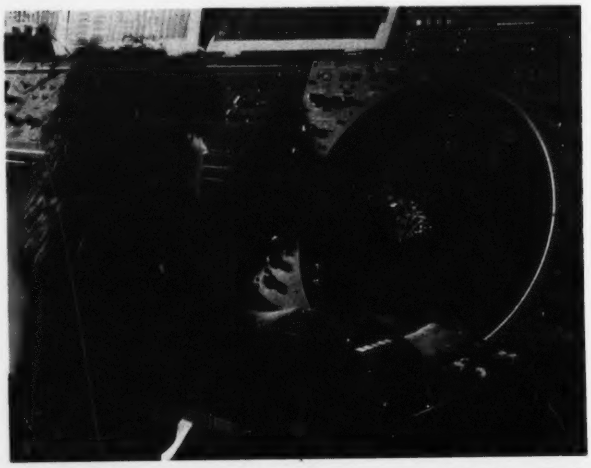
The Commission also consulted with INTELSAT in accordance with Article XIV(d) of the INTELSAT Agreement for transborder service to Canada, Mexico, Latin America, and other Caribbean countries. These services are carried on 33 domestic satellites that are operational or have been authorized for launch and operation through 1991 consistent with the 1988 Orbit Assignment Order. Similarly, the United States concurred in the INTELSAT consultation for the provision of transborder services to the United States from the Canadian Anik satellites and the Mexican Morelos satellites.

Department of Transportation

Two organizations within the Department of Transportation conduct major research and development programs in the field of aeronautics and space. These are the Federal Aviation Administration, one of the Department's modal administrations, and the Office of Commercial Space Transportation, which is a component of the Office of the Secretary.

Federal Aviation Administration

The Federal Aviation Administration (FAA) is charged with the dual mission of regulating air safety and fostering civil aviation. The agency engages in a broad range of research and development concerned with increasing safety, promoting aviation, and enhancing the efficiency of air navigation and air traffic control.



A controller operates ARTS IIIE equipment at the New York Terminal Approach Control Facility.

Aviation Safety

Traffic Alert and Collision Avoidance System

The Traffic Alert and Collision Avoidance System (TCAS) program reached important milestones during calendar year 1989 and fiscal year 1990. The system uses air-to-air interrogations between transponder-equipped aircraft to provide pilots with traffic advisories that indicate the range, bearing, and altitude of aircraft posing a potential threat. Some types of TCAS also provide a resolution advisory when conflicts occur between two aircraft carrying altitude-reporting transponders.

The program has three elements. The first, TCAS I, a low-power system that provides alerting information without recommended escape maneuvers, will be required in turbine-powered airplanes with 10 to 30 passenger seats by early 1995. FAA completed specifications for the system, and in 1989 awarded a contract for design, fabrication, and evaluation of six TCAS I units.

The second element, the TCAS II version, which provides not only traffic alerts but also resolution advisories that indicate whether the pilot should climb or descend, will be mandatory in all aircraft of more than 30 seats by December 31, 1993. In 1989, FAA completed the third TCAS II limited installation program, a six-month test involving two airliners, and awarded a contract to evaluate the system's use by commuter airlines. In 1990, the agency contracted for a program to monitor the system's national implementation, and certificated the first production TCAS II installation. More than 100 of the units had been installed by September 30, 1990.

TCAS III, the third element, generates traffic alerts and resolution advisories that include right/left turns as well as altitude changes. During 1989-90, FAA completed technical specifications for TCAS III and also completed two studies verifying that TCAS II units can be upgraded to TCAS III performance levels.

Aircraft Crashworthiness

The agency completed analysis of a new double-walled auxiliary fuel system, which demonstrated significantly improved rupture resistance under crash impact forces, and enhanced the program KRASH computer model that simulates impact effects. FAA conducted a full-scale vertical drop test of an Aero Commander 680E, a commuter-class aircraft with a high-wing design. The test yielded information on occupant survivability and data on metal structures that will be used for comparison with future tests on advanced composite structures. The agency also started collecting impact data on low-wing commuter aircraft, beginning with vertical drop tests on a Cessna 421B. FAA concluded new agreements with elements of

NASA and DOD for joint research on composite structures. With the Navy, the agency developed a method for estimating residual strength in damaged composite structures.

Aviation Weather

Low-Level Wind Shear Alert System. One of several FAA approaches to the hazard of wind shear, a sudden change in wind speed and direction, is the ground-based Low-Level Wind Shear Alert System (LLWAS) system, which uses computer processing to compare wind speed and direction from sensors located at the airport. The basic version generates an alert for air traffic controllers whenever center-field wind data differ significantly from data at the airport perimeter. By September 30, 1990, FAA had deployed 60 of the phase-two version, an upgraded system that provides an alert whenever any sensor's data deviate from the network average. The agency also contracted to further upgrade phase-two with new computers and software. In addition, FAA continued work on phase-three LLWAS, which has an expanded network of sensors and other enhancements. Two prototype phase-three systems were commissioned for operational use in 1988, and in 1990 FAA prepared to contract for seven more.

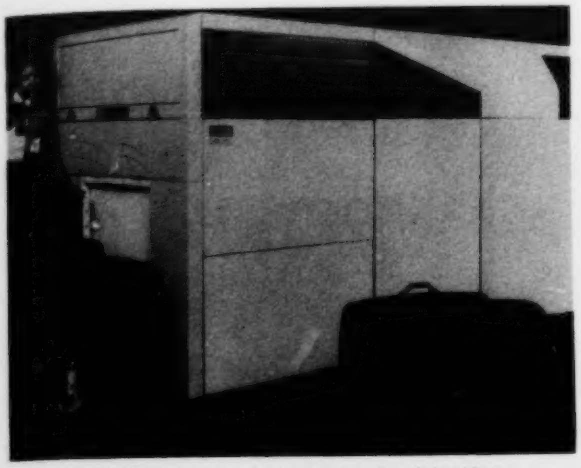
Terminal Doppler Weather Radar. FAA continued an operational evaluation of Terminal Doppler Weather Radar (TDWR) using two test radars, one at Denver and the other at Kansas City in 1989 and Orlando in 1990. Major objectives were to establish procedures for use of TDWR data, evaluate air traffic displays and the integration of wind shear warnings from TDWR and other systems, and determine if wind shear characteristics vary geographically. Radar output was displayed to air traffic controllers in real time. The evaluations supported procurement of 47 TDWR radars.

Airborne Wind Shear Program. In a joint program to develop system requirements for airborne wind shear detection and avoidance equipment, FAA and NASA have been assessing three promising sensor technologies that employ microwave radar, laser radar, or infrared devices. In 1989, the program emphasized flight-crew alerting and operational procedures, with tests yielding important data on the key question of how far in front of the aircraft the sensors need to look for timely hazard detection. In 1990, FAA and NASA executed a second agreement with the aim of developing advanced technology involving onboard sensors, reception and processing of ground-based data, and transmittal of airborne data to the ground.

A sensor for the Low Level Wind Shear Alert System, mounted on a tall steel pool.

Icing. FAA and the National Center for Atmospheric Research in 1989 began a six-year research program to develop improved forecast methods based upon data now routinely available and also to address basic research topics such as the formation of supercooled liquid water in the atmosphere. Other activities included publication of a three-volume Aircraft Icing Handbook for aircraft designers and certification engineers.

Automated Weather Observing System. The Automated Weather Observing System (AWOS) automatically collects a variety of weather data, analyses it, and provides round-the-clock weather forecasts to pilots by radio broadcast and telephone voice response. Besides providing grants for partial AWOS funding, FAA in 1988 ordered 160 of the advanced AWOS III systems for installation at airports without towers. The agency's first operational AWOS began service in 1989, and 50 more had been installed by September 30, 1990. FAA also continued its program to procure additional and more sophisticated Automated Surface Observing Systems.



The Thermal Neutron Analysis system for detecting explosives hidden in passenger-checked baggage.

Electromagnetic Environment Program. In cooperation with the Society of Automotive Engineers and industry, FAA produced a draft Advisory Circular and Users Manual on the hazards of electromagnetic radiation to flight. The agency published a Lightning Protection Handbook for certification specialists and design engineers, and Advisory Circulars on protecting aircraft from lightning's direct and indirect effects. FAA also prepared a draft plan for a research and development project on High Intensity Radiated Fields.

Aviation Security

The first of six thermal neutron analysis (TNA) systems purchased by the agency began operation in September 1989 at John F. Kennedy Airport. TNA is a high-technology explosives detection system capable of searching 600 passenger-checked bags per hour and able to detect all known commercial explosives, including plastics. By the end of 1990, the second, third, and fourth TNA systems were operational at airports serving Miami, Washington-Dulles, and London, England. An electronic device to provide an alternative, nonradioactive neutron source for the TNA system was successfully tested.

FAA-funded research to identify the next generation of explosives-detection systems showed promising results. Gamma-ray resonance absorption was demonstrated in the laboratory to be capable of detecting smaller quantities of explosives. Other new technology being considered by the agency includes millimeter wave imaging, a technique capable of detecting both metallic and nonmetallic weapons, and chemiluminescence explosive vapor detection.

The agency participated with Baltimore-Washington Airport's operator and air carriers in completing a conceptual design for upgrading all aspects of security at two concourses. The design is part of a long-term examination of an integrated systems approach to aviation security that includes such considerations as personnel selection, training, communications, technology, and architecture.

Airport Pavement Research

FAA developed criteria for coal tar's use to seal and protect airport pavements and for pavement design using alternative materials such as lime and fly ash. The agency sponsored research on employment of polymers for such purposes as runway repair and strengthening. FAA completed a successful three-year test of an improved pavement design method at an airport where severe frost damage had forced runway closure and also issued a survey-based report identifying research needed to address winter pavement distress. Other projects included work on a method of predicting pavement performance that will account for material characteristics and the mix of aircraft using the runway.

Human Factors Research

In 1989, a Government-industry task force reported on the need for human factors research to improve civil aviation performance and safety. In response to this initiative and to 1988 legislation, the FAA formed a Human Factors Coordinating Committee. With NASA and DOD, the Committee sponsored planning groups that prepared a draft National Plan for Aviation Human Factors to be released for public comment in early FY 1991.

In cooperation with NASA, the FAA investigated the effects of fatigue and circadian desynchronization on crew alertness during long over-water flights. As a result, FAA is studying regulatory actions allowing controlled rest periods on certain types of long-haul flights. NASA and FAA also continued evaluation of Cockpit Resource

Management (CRM) training. FAA issued a rule authorizing the Advanced Qualification Program, a new training approach in which CRM is mandatory.

The agency joined NASA and the Air force in a multi-year program to classify and evaluate pilots' strategies for coping with excessively low or high workloads. FAA also completed an initial report on development of a standard flight-crew error classification, and began analyzing data to determine human performance factors in commuter and air taxi crashes.

FAA developed a prototype that uses "expert systems" computer technology for realistic radar training exercises, demonstrated this system at Boston in 1989, and then in 1990 contracted for operational evaluation at two other locations. FAA also sponsored development of a prototype human factors course for certification personnel.

The agency initiated studies on human factors related to aircraft maintenance and inspection and to the need for revised analyses of the tasks of airway facilities maintenance technicians. Examples of the many other projects included the following: work to improve instrument approach chart design; flight simulator experiments on data link's use in hazardous weather alerting; and establishment of a working group to combat pilot/controller communications errors.

Other Safety Developments

Aging Aircraft. FAA published and then expanded its National Aging Aircraft Research Program Plan to deal with the problems of the aging transport fleet by addressing such issues as structural fatigue, corrosion, non-destructive testing, flight loads, and human factors. The agency sponsored the second annual International Aging Aircraft Conference in 1989 and participated in the third in 1990. FAA completed a survey of non-destructive inspection equipment and initiated work with NASA to assure coordination of research on aging aircraft problems. The agency developed a course on corrosion control, based on DOD work, and began offering this training to its own inspection personnel and to industry.

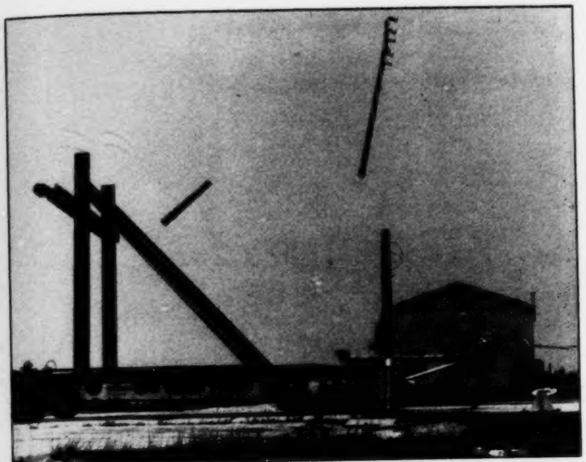
International Aircraft Operator Information System. The agency completed program and implementation plans for creation of a data collection and dissemination system to provide the latest airworthiness safety information quickly to all operators of U.S.-certificated aircraft.

A cabin safety fuselage burnthrough test after the fire was extinguished.

Turbine Engine Rotor Burst Protection. FAA completed the first phase of its cooperative project with the Army and Navy on the development of lightweight "soft wall" materials that can absorb and contain fragments from disintegrating turboshaft engine rotors. FAA also initiated two research contracts on soft wall and ceramic protective materials.

Aircraft Digital Systems. The agency conducted studies of flight-critical digital systems technology, in cooperation with NASA, and prepared handbook material on measuring software quality.

Aviation Fuels. FAA completed its evaluation of alternate fuels for light aircraft, concluding that piston engines and associated fuel systems would require significant modifications to permit safe use of gasoline-alcohol blends. Alcohol-derived ethers (either straight or blended with aviation gasoline) showed promise as alternate fuels for piston engines, despite some limitations. Small turbine engines would require some redesign to avoid operational problems with alternate fuels containing more than



An impact test of an approach lighting support tube as part of the Low Impact Resistance Structure development program.

15 percent alcohol, while blends containing less alcohol could also create certain problems. Flight tests showed performance decay in turbine engines during climb for all alcohol blends.

Aircraft Rescue and Firefighting. The agency began a major effort to establish firefighting requirements at general aviation airports and heliports through a program that will include full-scale tests simulating postcrash fuel fires. A new foam agent that reduces overall agent-to-water weight ratio was tested during 1989 and will be incorporated into the prototype of a new lightweight firefighting vehicle. FAA is also developing foam-agent specifications to assure uniform standards.

Fire Safety. Working with the Air Force, the agency in 1989 completed a four-year program to evaluate inflight cabin smoke evacuation. Major results included a valve with a converging-diverging nozzle that allows continuous smoke evacuation during descent and final approach, and a device that produces realistic, buoyant test smoke. FAA also completed a two-year burnthrough test program in which intact fuselages were exposed to large external fuel fires. The agency sponsored an international program in which 18 laboratories conducted smoke chamber tests of the same aircraft interior materials, which led to testing improvements. Working with Boeing, FAA completed a product definition study on an Aircraft Command in Emergency Situations (ACES) system to provide more timely and reliable information to the crew during an in-flight fire, and decided to develop an ACES prototype. Other aircraft systems fire safety projects included evaluation of an onboard cabin water-spray system, flight testing of hand-operated smoke evacuation valves, and work on a study of recycling Halon 1301 used for aircraft fire protection.

In 1990, FAA initiated a fuel-fire, risk-assessment program to identify the most probable causes of postcrash fires and promising prevention methods. The agency also continued a contract for small-scale tests to evaluate new fuel modifiers to minimize postcrash fire hazards.

Low Impact Resistance Structures. FAA continued developing Low Impact Resistance Structures (LIRS) to reduce damage to aircraft that might collide with air navigation equipment and supports. The agency participated with Commerce's National Institute of Standards and Technology in projects that included the following: development of analytical computer models; completion of an impact testing facility for LIRS components; design and testing of specialized electronic measurement systems; work on offshore LIRS design criteria; preliminary plans for field impact tests; and scheduling of a full-scale tower impact test.

Jet Engine Bird Hazard Program. The agency published an interim report on its worldwide collection of data on bird ingestion by commuter, executive, and Boeing 737 transport jet engines. The collected information will be used in upgrading airport and engine certification standards. FAA also completed the first year of a two-year study on bird ingestion in advanced, high-bypass turbofan engines installed on wide-bodied transports.

Medical Certification. FAA developed and will further refine computerized tests to detect cognitive deficits related to injury or diseases such as alcoholism. The agency completed a study on causes of medical certification denial for airline pilots, and conducted research on a variety of other topics such as the safety of beta-blockers and certain medications in treating hypertension in pilots.

Air Navigation and Air Traffic Control

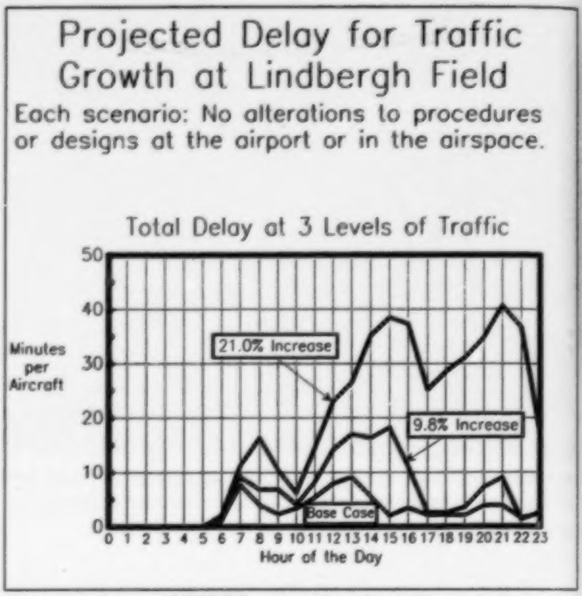
Air Traffic Control Modernization

Advanced Automation System. The wholly new Advanced Automation System (AAS) will replace the air traffic control automation equipment now used in en-route and terminal air traffic control. AAS will include new computer software, processors, controller workstations called "Sector Suites," and tower position consoles. The system will increase productivity, traffic capacity, and reliability and will provide the flexibility needed for future automation improvements.

In 1989, production began on the first segment of the program, the Peripheral Adapter Module Replacement Item. The contractor continued design work on other key system elements, and FAA in 1990 took delivery of the IBM 3090 Job Shop Processor, a part of the AAS system support computer complex.

Automated En-Route Air Traffic Control System. The Automated En-Route Air Traffic Control System (AERA) project will provide interactive software for use with the Advanced Automation System, improving airspace system capacity and efficiency through further automation. FAA made substantial progress on AERA-2, which provides controllers with advanced notice of potential problems and suggests resolutions. Laboratory evaluations of prototypes resulted in specifications for algorithms to accomplish problem resolution and computer-human interface. AERA-3, the most advanced phase of the program, will automate aircraft separation and many planning functions, enabling air traffic controllers to concentrate on managing the overall safe flow of traffic. In 1989 and 1990, three key functional AERA-3 elements were integrated into a "Protocenter" that is a basic prototype of an air route traffic control center. These elements were functions to ensure the following: that aircraft pairs never violate separation standards; that sufficient airspace is reserved for the safety of aircraft flying in clusters; and that the aircraft will meet metering requirements.

Advanced Traffic Management System. The Advanced Traffic Management System (ATMS) program goal is an evolutionary sequence of automation capabilities to enhance air traffic flow management. The Aircraft Situation Display system, which collects and displays real-time air traffic control data at the national flow control facility, was expanded to other major facilities during 1989-90. The Monitor Alert function, which provides automated alerts of projected congestion and delay, is being adapted for national use. In 1990, initial algorithms for automated generation of alternative flow management strategies were incorporated into the ATMS testing program.


Projected Delay for Traffic Growth at Lindbergh Field

Each scenario: No alterations to procedures or designs at the airport or in the airspace.

Example from a SIMMOD computer simulation study conducted by the FAA in 1989.

Voice Switching and Control System. This system will provide controllers at air traffic control centers with computer controlled voice switching for intercom, interphone, and air-ground communications. It will be more efficient and economical than the present electromechanical system. In 1989 and 1990, the agency began testing two prototype systems.

New York TRACON. FAA received the first benefits from a complex, two-stage program to increase the capacity of the New York TRACON (Terminal Radar Approach Control Facility), which services three major airports and 40 satellite airports. Stage I provides tracking of 1,700 aircraft within a 15,000-square-mile area, while

The Precision Runway Monitor prototype installed a Raleigh-Durham, NC.

Stage II will increase the tracking capability to 2,800 aircraft. In April 1989, FAA successfully placed the Stage I system in operation at the TRACON. After system testing at FAA's Technical Center, the Stage II hardware was installed at the TRACON in 1990 and on-site system testing began.

Aeronautical Data Link. FAA began operational demonstrations of Aeronautical Data Link applications for the new Pre-Departure Clearance procedure at three major airports. Clearances arriving from en-route traffic control centers were intercepted at prototype Tower Workstations and routed to the airline dispatch computers with local departure information automatically appended, except when local circumstances required voice intervention. Airlines then delivered clearances to their crews using the Aircraft Communications Addressing and Reporting System Very-High-Frequency data link and/or printers located at the departure gates. Results included delay reduction for participating carriers and relief of voice frequency congestion. The experience gained will be used to develop specifications for an interim Tower Workstation implementation at high-density terminals and help to define requirements for future data link capabilities.

Airport Visual Aids and Lights

The agency collected observations to test the effectiveness of standard taxiway signs, developed an improved marking of taxiway intersections, with associated lighting, and also completed a test plan for an operational evaluation of a self-contained, radioluminescent lighting system. In-service evaluation of an FAA-developed "hold-short" lighting system began at Boston Logan Airport during 1990.

Airport Capacity

Airport Capacity Design Teams. FAA continued to sponsor and participate in local airport capacity design teams that perform in-depth studies of current and anticipated demand levels, identify the causes of delay, and produce coordinated action plans. The teams quantify the benefits of various capacity enhancement actions and evaluate new technology applications. By September 30, 1990, plans had been completed for a total of 11 airports and were under way at 12 more. Over 400 task force projects had been designed, and six airports were considering new runways as a result of the studies.

Simulation Models. The agency continued to upgrade SIMMOD, a simulation model for airports and associated airspace that is an extremely cost effective method of addressing capacity and delay problems. SIMMOD has been acquired by nearly 100 users since its public release in late 1989. FAA expanded use of the National Airspace System Performance Capability, which simulates the entire en-route air traffic control system and the Nation's busiest airports, providing a quantitative foundation for FAA decisionmaking on issues that may have widespread effects on the airspace system. The agency also initiated efforts to develop a National Simulation Laboratory with large-scale, integrated capabilities that permit evaluation of new technologies, procedures, and global aviation concepts.

Precision Runway Monitor. The Precision Runway Monitor program's aim is to increase airport capacity through a safe reduction of constraints on use of parallel or converging runways during instrument meteorological conditions. FAA has developed prototypes of two versions of a monopulse radar much faster and more accurate than today's equipment. In one, an electronically scanned (E-scan) antenna updates the aircraft position every half second. The other version adds a second antenna to a Mode S type ground interrogator to achieve a 2.4-second update rate. Both systems have an improved radar display, automated predictor, and both visual and aural alerts. They are expected to reduce the spacing required between parallel runways used for simultaneous, independent parallel approaches from today's 4,300 feet to perhaps as low as 2,500 feet.

The Mode S type prototype was deployed at Memphis in 1988, and the E-scan prototype at Raleigh/Durham Airport in 1989. Operational demonstrations of both systems were conducted. Upon completion of the demonstration reports, a decision is expected as to whether the 4,300-foot spacing can be reduced and the update rate necessary to reduce it. The report tentatively recommends that a 2.4-second update rate is satisfactory for spacings 3,400 feet or greater, and further analysis will yield a recommendation for less than 3,400 feet.

Airport Surface Traffic Automation. The purpose of the Airport Surface Traffic Automation (ASTA) program is to develop techniques to prevent runway incursions and more fully automate control of aircraft ground movement, expediting traffic flow and increasing all-weather airport surface capacity. Program accomplishments included an initial ASTA-1 real-time simulation capability, an integrated system design, and a preliminary safety system description. FAA also contracted for operational evaluation of the Airport Movement Area Safety System, a commercially available system that detects possible incursions and alerts controllers. This early ASTA program product would be deployed at airports with the Airport Surface Detection Equipment (ASDE-3) radar system.

Terminal Air Traffic Control Automation. The Terminal Air Traffic Control Automation (TATCA) program is developing automation aids to increase terminal airspace capacity while enhancing safety and fuel efficiency. One project is a Converging Runway Display Aid (CRDA) that will allow dependent operations on both runways of a converging pair during instrument meteorological conditions, a procedure not presently permitted at most converging-runway airports. The aid will provide additional display information that will enable controllers to safely stagger approaches. In 1990, FAA was preparing CRDA algorithms for field evaluation, and also planning for field evaluation of the Center-TRACON Automation System (CTAS), which consists of three sets of integrated tools for providing advisories to controllers. These tools schedule arrivals to minimize delays, assist selection of conflict-free and fuel-efficient descent paths, and aid sequencing and spacing of aircraft on final approach. Other TATCA accomplishments included development of techniques for more accurately estimating winds aloft using radar surveillance data.

Satellite Applications for Civil Aviation

The U.S. Global Positioning System (GPS) will offer civil aviation another supplemental navigation aid, upgrade oceanic navigation, and improve approach and landing capability for the many airports not served by any instrument approach aid. For GPS to fully benefit U.S. aviation, international acceptance of satellite navigation is essential. In 1989, FAA initiated an activity with the Soviet Union, in cooperation with the International Civil Aviation Organization, to develop worldwide standards supporting these systems. Another of the rapidly emerging satellite applications for aviation is the Automatic Dependence Surveillance (ADS) technique, which will improve the safety and efficiency of oceanic flights by using data link to communicate the real-time positions of aircraft to control facilities. FAA's Oceanic Display and Planning System (ODAPS), an automated system to assist in controlling oceanic flights, is installed in California and New York. The West Coast ODAPS began limited operations, and preparations continued to make the second unit operational. ODAPS can be enhanced to accept ADS position reports via satellite and provide two-way data link between pilot and controller.

Synthetic Vision

The Synthetic Vision Technology Demonstration project is a multi-agency/industry cooperative effort jointly managed by FAA and the Air Force to develop a visual-

Synthetic vision technology uses a Heads-Up Display to present a processed image of the runway to the pilot of an incoming aircraft.

imaging system for very low visibility landing. Relying on millimeter-wave technology, the system will give pilots a processed image of the runway area. A contractor was selected to deliver a weather-penetrating sensor for incorporation into the demonstration system, and FAA also initiated a Government/industry, certification-issues study team that developed a draft Advisory Circular for the Synthetic Vision concept.

Rotorcraft/Powered-Lift Vehicles Program

Heliports and Vertiports. FAA published case studies of rotorcraft contributions to disaster relief, an analysis of rotorcraft operations at the successful Indianapolis Downtown Heliport, and the results of several tests on key heliport design parameters. Similar tests on vertiport parameters were planned, and approach lighting systems for rotorcraft instrument procedures were validated and documented in Advisory Circulars.

Civil Tiltrotor. In cooperation with industry and with other agencies, FAA completed a draft Civil Tiltrotor Implementation Plan. The agency formed a new Vertical Flight Program Office and a special advisory subcommittee on tiltrotor technology and its civil applications. The subcommittee held hearings in June 1990 and prepared a report on alternatives for producing tiltrotors and the technology's potential for commercial use, export, and the relief of airport congestion. FAA and NASA completed Phase II of their joint Civil Tiltrotor Missions and Applications Study, which offers new insights into such issues as civil tiltrotor designs, costs, markets, possible risk areas, and recommended additional research. FAA began an overall economic analysis of national tiltrotor implementation, and 15 local governments continued vertiport feasibility studies under Airport Improvement Program grants.

Rotorcraft Training and Safety. FAA completed a multi-year effort with the publication of the last of four volumes on Aeronautical Decision Making training for helicopter emergency service personnel. The agency began flight demonstrations and analysis of night-vision goggles to determine their suitability for civil rotorcraft use in low-visibility conditions. FAA conducted research on advanced procedures for approaches to heliports and investigated the use of side-stick and side-arm manipulators for rotorcraft and tiltrotors. The agency also conducted a comprehensive review of accidents to develop data on crash-resistant fuel systems for rotorcraft and planned a series of rotorcraft drop tests.

Commercial Space Transportation

Fiscal years 1989 and 1990 were turning points for the Department of Transportation's Office of Commercial Space Transportation and the U.S. commercial launch industry. The first suborbital and orbital U.S. commercial launches licensed under the Commercial Space Launch Act began during FY 1989: on March 29, 1989, Space Services Inc. of America conducted a suborbital launch from the White Sands Missile Range in New Mexico. The two-stage Black Brant rocket carried a payload of several materials-processing experiments designed by the University of Alabama—Huntsville Consortium for Materials Development. On August 27, 1989, a McDonnell Douglas Delta rocket lifted off from Cape Canaveral carrying a British Satellite Broadcasting Co. communications satellite. A total of 10 successful launches took place during fiscal years 1989 and 1990.

Key achievements for FYs 1989 and 1990 included the following: 14 commercial launch licenses and six Commercial Launch Manifests were issued. The latest manifest, issued in July 1990, lists a total of 35 commercial launch contracts.

State of the U.S. Commercial Launch Industry

Launch Services Companies. As of the end of fiscal year 1990, at least six U.S. launch firms were actively marketing their services on a national and/or worldwide basis. These included three major aerospace companies—General Dynamics Commercial Launch Services, McDonnell Douglas Commercial Delta, Inc., and Martin Marietta Commercial Titan, Inc.—as well as several smaller firms.

Commercial Space Transportation Infrastructure

U.S. firms currently rely upon the existing national launch infrastructure to support their operations. This infrastructure consists of several launch sites and facilities which are made available on a direct cost-reimbursable basis to commercial launch firms under the provisions of the Commercial Space Launch Act, as amended.

An important development in this area has been the intentions of several States to consider constructing or developing commercial spaceports. The principal domestic spaceport initiatives are those for Hawaii, Florida, and Virginia.

Hawaii. In April 1988, the State of Hawaii completed a feasibility study and made the preliminary selection of two possible commercial space launch sites—Palima Point and Kahilipali Point—on the Island of Hawaii. After approval of funding by the legislature, the State recently began studies to prepare a master plan and an Environmental Impact Statement (EIS) for the proposed spaceport. The EIS process began in September 1989, with joint Federal/State participation, and it is scheduled to be completed by the end of 1990.

In the summer of 1989, Hawaii requested a preliminary determination from the Office of Commercial Space Transportation as to the suitability of the two alternative sites. The Office conducted a study to determine whether launch activities may be safely conducted from either or both sites, the results of which were issued in a report entitled, "Safety Assessment of Two Proposed Hawaii Launch Sites: Palima Point and Kahilipali Point." A determination was made that both sites are acceptable from a safety perspective as candidate commercial launch sites.

Florida. In 1988, the State of Florida commissioned a feasibility study on the prospects for commercial spaceports. This study, which was released in February 1989, identified potential launch sites and urged State officials to move quickly on the spaceport initiative. The Florida legislature created the Spaceport Florida Authority in June 1989. The Authority is charged with overseeing the development of commercial launch complexes at or near Cape Canaveral Air Force Station and Cape San Blas in the Panhandle.

Virginia. The Commonwealth of Virginia has also been exploring the feasibility of establishing launch sites dedicated to commercial launches at either a Federal or a non-Federal location within the Commonwealth. In particular, Virginia's Center for Innovative Technology is seeking commercial space possibilities that could lead to small satellite launches from NASA's Wallops Island Flight Facility.

On the foreign scene, a feasibility study on a possible commercial launch facility at Australia's Cape York peninsula was completed by the Cape York Space Agency in 1989. The agency is proposing to launch Soviet-built Zenit rockets from the facility. A U.S. company, USBI, a subsidiary of United Technologies, applied for an export license to serve as project manager of the launch facility. In August 1990, President Bush approved the export license. Construction of the facility could begin as early as 1992 and be completed in 1995.

International Competition

Currently, the world commercial launch services market is dominated by the U.S. and European launch companies. However, because of Arianespace's greater presence in earlier years, it still leads in terms of outstanding launch contracts. In total, the U.S. commercial launch firms have outstanding contracts to launch 22 orbital payloads, whereas Arianespace has outstanding contracts for 35.

The People's Republic of China has been marketing launch services since 1984 and currently holds two firm commercial launch contracts. The Soviet Union is also marketing launch services, although as of September 1990 it still had not secured contracts to launch Western-built satellites.

Licensing and Regulatory Program

Licensing Activity. The 14 commercial launch licenses issued during fiscal years 1989 and 1990 were distributed among five companies: Space Services Inc. of America, McDonnell Douglas Corporation, Martin Marietta Commercial Titan, Inc., General Dynamics Commercial Launch Services, and American Rocket Company.

Insurance Requirements. In November 1988, Congress enacted the Commercial Space Launch Act Amendments of 1988 (Amendments), which established comprehensive financial responsibility requirements and allocation of risk principles applicable to commercial launch activities licensed by the Office of Commercial Space Transportation. The Amendments require, among other things, that financial responsibility requirements be based on a determination of the actual risks associated with each proposed activity. Prior to passage of the legislation, the Office of Commercial Space Transportation had been relying on this approach as a matter of general policy.

In 1989 and 1990, in accordance with the Amendments, the Office of Commercial Space Transportation crafted specific insurance and related financial responsibility requirements covering the licensed launch activities of seven companies: McDonnell Douglas, American Rocket Company, Martin Marietta Commercial Titan, Inc., General Dynamics Commercial Launch Services, Space Services Inc. of America, Orbital Sciences Corporation, and LTV. A regulatory proposal is currently being developed to codify the Office's approach to establishing appropriate levels of insurance and other financial responsibility requirements.

Research for Regulatory Functions. The Office of Commercial Space Transportation has conducted a comprehensive review of safety data compiled by various Government agencies, identified information gaps, and initiated studies to fill these gaps and enable us to fulfill our regulatory responsibilities. The Office also conducted several studies on the ability of the commercial launch industry to develop and remain competitive. Some studies focused on scheduling procedures at U.S. launch ranges, the availability of commercially reasonable launch facilities, and the effects of Government procurement practices on commercial launch costs. Some examples of the research follow:

- ***Scheduling Commercial Launch Operations at National Ranges.*** As required by Section 6 of the Amendments, the Office of Commercial Space Transportation conducted a study and issued a report on the scheduling of commercial launch operations at U.S. launch ranges. The study report, entitled "A Study of the Scheduling of Commercial Launch Operations at National Ranges," examined the issues associated with commercial launch companies using the facilities and resources at national ranges and the impact of current practices on the competitive stance of U.S. commercial launch firms in the international launch services market.

- ***Commercial Baseline Assessments.*** The Office of Commercial Space Transportation documented the capabilities of the national ranges to handle commercial operations. Baseline assessments for Vandenberg Air Force Base in California and Wallops Island in Virginia were completed in 1989. This follows the assessment of Cape Canaveral Air Force Station in Florida in 1988. An assessment for White Sands in New Mexico is under way and will be completed in 1990.

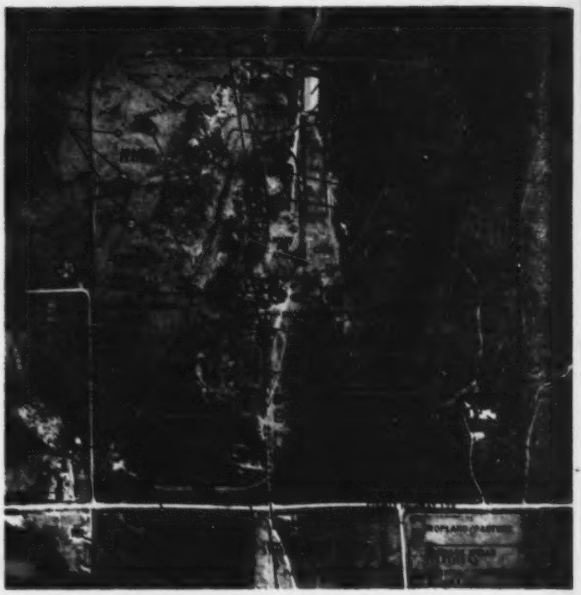
- ***Orbital Debris.*** OCST contributed research data concerning space debris for the "Interagency Report on Orbital Debris," issued in February 1989.

- ***Research Supporting Future Rulemaking and Licensing Activities.*** The Office is assembling resources to support a number of rulemaking actions. One rulemaking action will focus on codifying the Office's approach to setting appropriate levels and terms of financial responsibility, acceptable forms of coverage, and allowable exclusions.

Other areas of activity will involve several major changes in the licensing process which will move the Office away from a case-by-case evaluation procedure for launch and pre-launch activities toward an integrated regulatory model covering both site and launch operations.

Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA), through its Environmental Monitoring Systems Laboratory in Las Vegas, NV, routinely conducts research and technical support using remote sensing as part of an overall environmental monitoring program. Large-scale aerial photography is collected and interpreted to support the provisions of the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); medium-scale photography is collected and interpreted to support non-point-source pollution studies, wetlands protection, coastal-zone studies, and forest-ecosystem decline caused by acid deposition; and high-altitude photography is interpreted for broad area studies in the coastal zone and to contribute land-use and land-cover information in risk-assessment studies. Airborne and satellite multispectral scanner data are collected and interpreted to support water-quality, non-point-source pollution, hazardous-waste, and critical-habitat investigations. Airborne laser systems are developed which contribute to air and water monitoring, and a geographic information system is used to integrate multiple data sets in support of all EPA programs.



PhotoInterpretation analysis of hazardous waste site using large-scale vertical aerial photography.

Hazardous Waste

Large-scale aerial photography is used to develop site characterization data during the remedial investigation and feasibility study portion of remedial actions under CERCLA (the Superfund) and may be used to support ranking under the site identification. Aerial photographs are collected from a variety of archival sources which may date from the late 1920s and continue to the present. A site history is developed by visually interpreting the historical photography, annotating changes at the site. This provides vital information on the location of drums, pits, and lagoons, as well as the level of activity at the site over time. Further, photographic interpretations provide documentation of cleanup progress and are sometimes used to monitor post-cleanup status. The same photographs are also used to develop detailed topographic maps of each site which are critical to the cleanup process. The opening illustration shows the interpretation of a single date of this photography at a Superfund site. Repeated interpretations of photography of different dates provides a permanent record of the site's history for litigation and cleanup.

Aerial photography is also used to support site selection and monitoring at hazardous waste facilities operating under the Resource Conservation and Recovery Act. During the site selection process, aerial photographs, airborne multispectral scanner data, and satellite imagery are interpreted to develop a detailed site characterization. The interpretations are then used with collateral data (such as soils, geology, and groundwater data) to determine applicability under the site-selection criteria. Aerial photography is routinely used to monitor development, operation, and closure activities once a site has been approved for operation.

Aerial photography also supports emergency actions during spills and accidents. Photographs are acquired through local contractors and are interpreted and sent to the field within 24 to 48 hours of an accident or spill. These photographs of existing conditions form a permanent record of the on-scene conditions and are used to develop control and remedial strategies.

Water Quality

Remote sensing systems are developed and used by EPA to support the provisions of the Clean Water Act. The Landsat satellite system and an airborne multispectral scanner are used in conjunction with water samples to map the extent of *Chlorophyll a*, Secchi depth, turbidity, dissolved organic carbon, and a variety of other water-quality parameters in both freshwater lakes and near-coastal marine environments. A Laser Fluorosensor system is under development to augment the passive scanner systems, increasing the number of variables measured and the accuracy of measurement of current variables. Currently, the system is being updated to permit finer interpretation of spectral response, resulting in more accurate determinations of water-quality variables, and laboratory analyses are being conducted to develop the methods for monitoring blue-green algae in aquatic systems.

Aerial photography and satellite data also support non-point-source pollution studies. Satellite imagery provides the broad view of land cover, while aerial photographs provide detailed interpretations of the distributions of feeder lots, poultry farms, and other activities requiring high spatial resolution. These data are used as inputs to models of pollutant transport to estimate the migration of nutrients and toxics into surface and subsurface water systems. For example, the Blackfoot River system was studied using satellite remote sensing to determine non-point-source inputs to Lake Pend Orielle, ID. Algal blooms in Lake Pend Orielle are related to nutrients from the surrounding watershed. The remote sensing provided land-cover inputs to the WRENS (Water Resources Evaluation for Silvaculture) model which was used to simulate alternative non-point-source management scenarios.

Air Quality

EPA is currently using an airborne, two-frequency LIDAR (Light Detection and Ranging) laser radar system to monitor particulates associated with major urban plumes and emissions sources and is developing (with NASA support) an airborne Ultraviolet Differential Absorption LIDAR (UV DIAL) to simultaneously measure ozone, sulfur dioxide, and particulates. These instruments provide range-resolved profiles under the aircraft which can be used to monitor pollutant transport in coastal areas and complex terrain where models function poorly and where air-pollution transport problems are most severe.

Currently, the LIDAR system is being used, with other measurements, to determine the extent of the Denver Brown Cloud and to develop an understanding of the movement of air pollutants between El Paso, TX and Juarez, Mexico.

EPA, in conjunction with the U.S. National Park Service, is also conducting remote measurements of visibility in Class I areas (National Parks and Wilderness Areas). Photographic and electro-optical sensors are deployed to monitor scenic vistas to determine atmospheric extinction coefficients. Variations in extinction coefficients are then related to variations in air-pollutant levels. Models are then used to predict the visual impact of emerging legislation on both wilderness areas and on urban scenes. The photographs are then systematically altered to show the effects predicted over a series of air-quality scenarios.

Ecological Risk Assessment

EPA has championed a new interagency program, designed to determine long-term status and trends in the Nation's ecological resources. The program, called the Environmental Monitoring and Assessment Program, uses both remote sensing and field study to characterize the landscape and to monitor indicators of ecological health in the Nation's wetlands, near-coastal systems, Great Lakes, forests, agricultural lands, inland waters, and arid lands. Satellite remote sensing and aerial photography interpretation will be integrated to describe the pattern of the landscape at over 12,000 sample locations throughout the United States. These patterns will be monitored at a minimum of 10-year intervals to determine changes in the Nation's ecosystems, and the resulting database will potentially provide a valuable stimulus to the study of the Nation's landscape ecology. Field study of over 3,000 sites will be used to determine status and trends of indicators of ecological health, providing vital information on condition of ecosystems as part of the puzzle for determining ecological risk. The information derived throughout this program will be shared through the use of an integrated information system which is being designed to make use of state-of-the-art distributed computer networks. This information will be of critical concern to policymakers including the President, members of Congress, and the public.

Data Integration

Often, single-media monitoring and modeling do not provide sufficient scientific explanation of the complex environmental phenomena which affect human and ecological health. A geographic information system (GIS) has been implemented in EPA to provide a tool for multimedia data integration and analysis. The GIS is used to overlay and combine data from remote sensing, existing spatial databases, and tabular data from State, local, and EPA national databases to provide analyses of complex environmental situations for programs such as wetlands and estuarine protection, water quality, acid deposition, the Environmental Monitoring and Assessment Program, global change, and hazardous waste cleanup.

Interagency Cooperation

The EPA is working with other Federal agencies, State, and local governments to assure coordination of activities in environmental monitoring. The Environmental Monitoring and Assessment Program, in particular, is designed to promote interagency information exchange and cooperation by including other agencies in important planning and implementation roles. EPA is working closely with NASA, NOAA, USGS, and other agencies to assure that, as NASA's Mission to Planet Earth develops, we will be able to use the newly developed space sensing systems to monitor ecosystem condition and to detect global change.

National Science Foundation

The National Science Foundation (NSF) is the principal supporter of academic research in atmospheric sciences and ground-based astronomy. NSF support is provided partly through grants to individual investigators, and partly through contracts and cooperative agreements with universities and consortia operating observatories and other large facilities.

The National Science Foundation is a major participant in the U.S. Global Change Research Program, an interagency program designated as a Presidential initiative in January 1989. This program comprises both space-based and ground-based research thrusts in several critical areas, including the atmospheric sciences.

Astronomical Sciences

The success of NASA's Voyager 2 spacecraft's encounter with Neptune and its moon, Triton, in the summer of 1989, was significantly aided by the Very Large Array (VLA). The VLA, a radio telescope located in New Mexico, was used in combination with NASA's Deep Space Network to acquire data relayed by the spacecraft. Approximately 50 percent more data were recorded than would have been recovered without the VLA.

The VLA was also used by astronomers to map the moon of a planet other than Earth by radar reflections for the first time. Observations of Saturn's moon, Titan, have shown that the reflectivity of the surface is consistent with the presence of a deep methane ocean but that such an ocean could not be spread uniformly over Titan's surface.

Astronomers mapped the galaxy distribution in the nearby universe. This revealed large coherent structures, which consist of thin, sheet-like features, where most of the galaxies are concentrated, and large voids interspersed between them. The extent of the largest features is limited only by the portions of the universe surveyed so far. This picture poses a challenge to the current understanding of the origin and evolution of the universe which requires the assumption of a more homogeneous distribution of matter.

Astronomers reported the discovery of a population of faint blue galaxies that could have been the first formed in the universe. The galaxies were detected by using the latest charge-coupled device technology (sensitive, two-dimensional sensors), and by pushing observing and image-processing technologies to their limits.

A short exposure of the sun's disk and a longer exposure of the sun's limb, both taken on June 20, 1989, are combined to show both the solar flare against the disk and the associated erupting prominence over the limb. This composite photograph (prepared by Big Bear Solar Observatory, Big Bear City, CA) illustrates the highly active sun as seen during the second most active solar maximum period since such events began to be recorded.

Cosmologists at Amundsen-Scott South Pole Station made measurements of the absolute intensity of the cosmic microwave background radiation (CMBR) at five wavelengths at the same time that the newly launched NASA Cosmic Background Explorer satellite was making similar measurements at shorter wavelengths. This combined effort allowed the CMBR spectrum to be measured over a wider wavelength range than is possible from either Earth or from space.

Atmospheric Sciences

MAX'91 is a coordinated program between NSF and NASA to study solar disturbances. One of the greatest solar activity maxima in recorded history should occur during 1990. The first MAX'91 campaign to study the active solar output was conducted in June and July 1989. Ground-based measurements from several observatories were coordinated with satellite measurements from the Solar Maximum Mission (SMM) satellite, to provide measurements relating to the variable solar output in a wide spectral range of radiations. This campaign has already permitted comparisons of solar flare outputs, such as visible and ultraviolet light, and even energetic x-rays. Such information is critical to understanding solar outputs and their impact on Earth's atmosphere, an important element in the U.S. Global Change Research Program. MAX'91 will be continued in 1990, albeit without SMM, which was lost when it reentered Earth's atmosphere in December 1989.

In 1989, investigators using NSF-funded telescopes reported that by studying a large sample of solar-like stars, one can observe the states of activity that our own sun may have experienced, both in the past and possibly in the future. They reported that about one-third of such stars currently exist in a dormant mode, approximating the Maunder minimum (or Little Ice Age) of the 17th century. The investigators also observed that most solar-like stars show solar activity cycles similar to our sun's 11-year solar cycle. By studying the characteristics of such stars, it should be possible to estimate the probability and frequency with which our sun moves into periods of low and high activity, or into passive periods resembling the Maunder minimum. Such estimates would have an impact on our projections for future trends in global climate change.

Measurements were made at South Pole Station and Palmer Station, Antarctica, of very-low-frequency radio waves transmitted by the Soviet satellite AKTIVNY, launched to study wave-particle interactions in Earth's magnetosphere. This is a project of NASA and the Soviet space agency IKI.

NSF's ultraviolet (UV) radiation monitoring system was established in 1988 at South Pole, McMurdo, and Palmer Stations in Antarctica, and in Ushuaia, Argentina, to provide high-quality data on the levels of incident UV radiation associated with ozone depletion over Antarctica. During 1989, instrumentation was upgraded to improve temperature tolerance and reliability. A data center with high standards of quality assurance was created in 1989 to provide a data directory and reduced data to researchers worldwide. The data from this monitoring system serve as a standard for all related research on UV influx and its effects on biological systems in Antarctica and its surrounding ocean. These data were used this year to corroborate satellite-born Total Ozone Monitoring Spectrometer (TOMS) data.

NSF provided support for a team of NASA Goddard Space Flight Center researchers to fly ozonesonde balloons from Palmer Station, Antarctica during the austral spring of 1989 and 1990, when stratospheric ozone is formed. At the same time NASA provided satellite ozone maps from the Total Ozone Mapping Spectrometer (TOMS) to NSF-sponsored researchers in Antarctica.

In January 1990, two large balloons (28 and 13 million cubic feet) were launched by NASA from McMurdo Station, Antarctica. The payload included a gamma ray detector to study the sun and Supernova 1987a, a cosmic ray detector, and an X-ray camera to image the aurora. Unfortunately both flights were terminated prematurely because of balloon system failure. An attempt will be made to refly the experiments during the 1990-1991 season.

Smithsonian Institution

The Smithsonian Institution participates in national space programs through basic research conducted at the Smithsonian Astrophysical Observatory (SAO) in Cambridge, MA, and at the Center for Earth and Planetary Studies (CEPS) and the Laboratory for Astrophysics (LfA) at the National Air and Space Museum in Washington, DC. The Museum's exhibits, lectures, and education programs also contribute to public understanding of space research and exploration. SAO also conducts programs designed to improve pre-college science instruction and serves as the U.S. gateway for SIMBAD, an international astronomical computer database.

Space Science

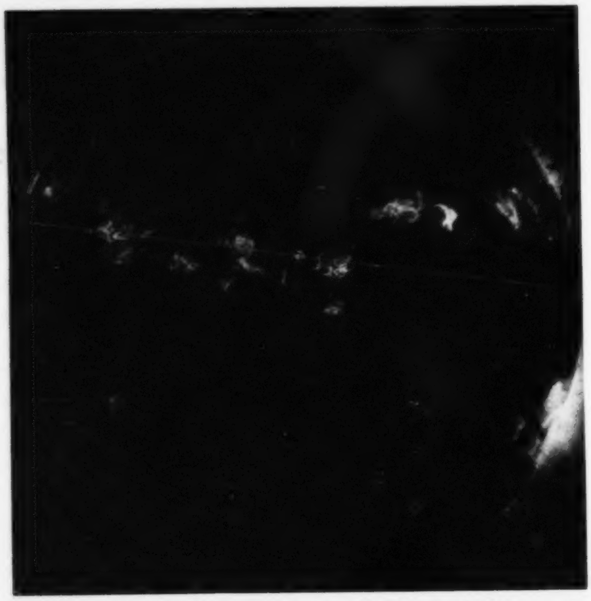
High-Energy Astrophysics

Launched June 1, 1990, Roentgen satellite (ROSAT, a joint project among the Federal Republic of Germany, the United Kingdom, and the United States) will map the entire sky in x-rays and then use a High-Resolution Imager built at SAO to make detailed studies of selected objects. Test images taken in July included a "first light" observation of the Cygnus X-2 compact binary, a cluster of galaxies, the Cas A supernova remnant, and a landmark image of the moon. SAO is operating the U.S. ROSAT Data Center in cooperation with the Goddard Space Flight Center.

Each year since the last focused images of cosmic x-ray sources were obtained a decade ago, scientists from around the world have come to SAO to use data from the Einstein (HEAO-2) Observatory. In 1989, this information was converted to CD-ROM format by SAO and made available free to all qualified scholars.

Although the Einstein Observatory produced 5,000 images during its 18-month lifetime, SAO researchers felt some valuable data had been overlooked. When Einstein's telescope slewed from one "pointed" observation to another in a different part of the sky, its detectors also recorded the strips of sky along the way. A computer program was devised to reconstruct these thin strips into a "slew survey catalog" of some 1,000 bright x-ray objects, half of which had not been seen before.

In March 1989, the third largest solar flare ever recorded was observed by a rocket-borne x-ray telescope built by SAO and IBM's Watson Research Center. The Normal Incidence X-ray Telescope obtained high-resolution x-ray images on the flare's onset phase, which, when combined with simultaneous observations in other wavelengths, provide new insights into these eruptive events. A subsequent flight in September 1989 produced the highest-resolution x-ray images to date of the sun's outer atmosphere, or corona.



The highest resolution x-ray image ever obtained of the sun's corona was taken September 11, 1989 by a Smithsonian Astrophysical Observatory/IBM telescope aboard a NASA sounding rocket launched from White Sands Missile Range, NM. Boosted to a height of 150 miles, the Normal Incidence X-ray Telescope observed the sun for five minutes and took 38 frames of film before parachuting back to Earth. The images revealed hitherto unseen details of active regions (bright areas) as well as of a medium-sized solar flare, which probably reached temperatures of 10 million degrees Celsius, and a dark solar prominence. X-ray "bright points" were clearly resolved into loops at the center of the image. (Smithsonian Astrophysical Observatory and the IBM Thomas J. Watson Research Center photo)

A balloon-borne Energetic X-ray Imaging Telescope Experiment, a joint Harvard-SAO experiment, was successfully flown from Alice Springs, Australia, in May 1989.

During the 30-hour flight, the experiment observed many x-ray-emitting objects, including the Crab Nebula, Supernova 1987a, x-ray binaries, a black hole candidate, and a globular cluster containing a millisecond pulsar.

Solar Physics

One of the outstanding problems in solar physics is determining the mechanism responsible for heating the outer atmosphere of the sun and accelerating particles from it to form the solar wind, which then streams into interplanetary space. In anticipation of flight aboard the Solar Heliospheric Observatory in 1995, SAO scientists are designing an Ultraviolet Coronal Spectrometer to seek how and where the solar wind is accelerated.

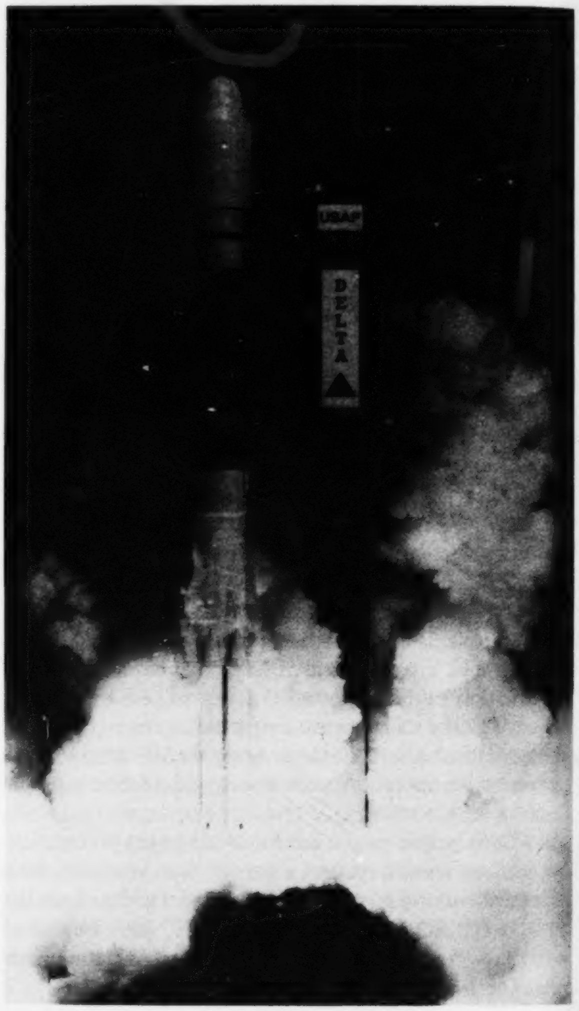
Stellar and Galactic Studies

Using infrared detector arrays and Fabry-Perot spectrometers, Laboratory for Astrophysics (LfA) scientists obtained spectral images of regions of star formation in molecular clouds and of shocked and ionized gas in colliding and active galaxies. Theoretical aspects of the research centered on models of intergalaxy collisions and line shapes from ionized winds in young stellar outflows. The database created by the Infrared Astronomy Satellite was used extensively in this program.

As part of NASA's Small Explorer Program, SAO will build and operate a Submillimeter Wave Astronomy Satellite for planned launch in 1994 to study how molecular clouds in the Milky Way collapse to form stars and planets.

Lunar Studies

Nearly two decades after the Apollo astronauts returned samples of lunar soil, a completely new rock type was identified on the moon by an SAO scientist sifting through the old material. Tiny grains of a magnesium-rich mineral called cordierite, usually present only in very deep geological deposits, were found in a collection from the Apollo 15 mission. Presence of the rare mineral on the lunar surface suggests it was "excavated" by a meteorite impact, perhaps the same one that created the Imbrium Basin near where the sample was collected.



The joint F.R.G.-U.K.-U.S. ROSAT (Roentgen satellite) was launched into a near-perfect orbit by a Delta II rocket from Cape Canaveral, FL, on June 1, 1990. The largest x-ray telescope ever flown, ROSAT is equipped with a High-Resolution Imager built by the Smithsonian Astrophysical Observatory to provide focused images of cosmic x-ray sources. The ROSAT mission will make a map of the entire sky in x rays as well as detailed studies of selected objects. Test observations made with the High-Resolution Imager in July included images of the compact x-ray binary Cygnus X-2, the Cas A supernova remnant, a cluster of galaxies, and the moon. (NASA photo)

Terrestrial Studies

During 1989 and 1990, CEPS staff addressed several issues of global change related to ongoing studies of remote-sensing data on arid and semi-arid regions. For example, investigations of Earth's deserts included the comparison of Landsat images of the Selima sand sheet in southwestern Egypt with field analyses to estimate sediment transport budgets for chevron-shaped bedforms. In addition, reflectance characteristics and surface processes in stabilized dune environments in Egypt, Mali, and Botswana were studied using multi-temporal Landsat data. In the area of terrestrial tectonics, evidence of reactivation of the Najd fault system of central Arabia was analyzed by using AVHRR (Advanced Very High Resolution Radiometer), Landsat, and SPOT (the French *Satellite pour l'Observation de la Terre*) data. A kinematic and mechanical analysis of periodically spaced folds in the continental flood-basalts of the Columbia Plateau in northwestern United States was also completed.

Three flights of SAO's balloon-borne infrared spectrometer in 1989 and 1990 obtained spectra of several important stratospheric molecules. How the abundances of molecules such as ozone, carbon dioxide, hydrogen peroxide, and hydroxyl vary with both time and altitude is now being analyzed as part of the effort to determine what processes may preserve or destroy Earth's protective shield of atmosphere.

Planetary Sciences

Research in planetary geology at CEPS continued with the analysis and comparison of crustal deformation on Earth, Mars, and Venus. Detailed 1:500,000 mapping of parts of Mars not only contributes to understanding that planet's geologic history, but may help select potential landing sites for future missions. The migration of dust deposits on Mars under the present climatic conditions was investigated, as was the timing and mechanisms for erosional and depositional modification of surfaces in Mars' eastern hemisphere.

In research complementing various planetary flyby missions, the LfA used infrared heterodyne spectroscopy to measure absolute wind velocities in the atmospheres of Venus, Mars, and Jupiter, and to model the tropospheres/mesospheres of these planets.

Department of State

The Department of State is responsible for evaluating and advancing U.S. foreign-policy interests in space activity. It evaluates the foreign-policy aspects of space programs, policies, and agreements, and advises the President on international space matters. In addition to these responsibilities, State represents the U.S. Government in international government-to-government negotiations involved in space.

The 1988 International Agreement on Space Station Cooperation calls for a government-level meeting to be held every three years to review space station cooperation and issues involving it. The first of these meetings was held at the Department of State in September 1989. Representatives of each of the governments participating in this cooperative venture—the United States, nine members of the European Space Agency, Japan, and Canada—attended. The principal topic of discussion was the impact of an anticipated cut in the Bush Administration's budget request for space station activities. The meeting concluded with a joint statement emphasizing the partners' commitment to "continue to consult and to work together to preserve the international character of the project and the balance of mutual benefits and responsibilities reflecting the genuine partnership set forth in the agreements."

The Department has worked with NASA throughout this period to support the space shuttle program. State Department activities have included continued work on negotiation of agreements for emergency-landing facilities in other nations, and activation of a Space Shuttle Task Force for each shuttle launch to provide a direct link to U.S. embassies in countries where emergency-landing facilities are located. In addition, the State Department has worked with NASA and other agencies on charting a course for future human exploration of space. Deliberations aimed at producing recommendations on how to implement the President's moon-Mars initiative began within the National Space Council in late 1989. The feasibility of international cooperation in carrying out a manned mission to the moon and Mars has been a question of particular interest to the State Department. The Department also took part in the National Space Council proceedings that resulted in the continuation of the National Aero-Space Plane program.

In addition to U.S. policy implementation and bilateral negotiations, the Department of State represents the U.S. Government in international organizations involved in space issues. These include the United Nations and related organizations such as the International Telecommunications Union, INTELSAT (International Telecommunications Satellite Organizations), and INMARSAT (International Maritime Satellite Organization).

U.N. Committee on the Peaceful Uses of Outer Space

The 53-member U.N. Committee on the Peaceful Uses of Outer Space (COPUOS), its Scientific and Technical Subcommittee, and its Legal Subcommittee all met during 1990. For several decades after its inception in 1958, the Committee worked successfully in the exchange of scientific information and negotiated four widely accepted conventions that form the basis of international space law. However, during the 1970s and early 1980s, the scientific and legal work of the Committee became attenuated, with debates becoming increasingly political. In the last five years, however, the United States has worked closely with other delegations, particularly with Western delegations, to reinvigorate the scientific content of the Committee's work. Notable progress has been made with the incorporation of U.S. proposals dealing with astronomy, planetary exploration, and the geosphere/biosphere onto the agenda of the Scientific and Technical Subcommittee, as well as an item concerning spin-offs from space programs onto the agenda of COPUOS.

At the February 1990 Scientific and Technical Subcommittee meeting, member states focused on the use of space technology for search-and-rescue problems. The Subcommittee decided to pay particular attention to the use of space technology in disaster relief activities. The Legal Subcommittee met in March 1990 to consider questions relating to the use of nuclear-power sources in space, utilization of geostationary orbit, and the delimitation of outer space. The Subcommittee also continued its consideration of the new agenda item on dealing with the application of the principle that space exploration should be carried out for the benefit of all countries, taking particular account of the needs of developing countries.

In 1990, the United States, with the support of other Western countries, continued efforts to make the work of COPUOS and the Subcommittee more relevant to the present state of space exploration. To this end, at its June 1990 meeting, member states agreed on a U.S. proposal concerning the International Space Year (ISY). This topic was first proposed by the United States at the 1988 session of COPUOS. On the basis of a joint resolution of Congress in 1986, which was endorsed by President Reagan, international scientific organizations and national space agencies will celebrate 1992 as the International Space Year. COPUOS recommended, and the General Assembly has since agreed, that it could play a meaningful role in ISY without any impact on the regular budget of the United Nations through the training and education capabilities of the U.N. Programme on Space Applications.

International Maritime Satellite Organization

At its 36th session, in July 1990, the International Maritime Satellite Organization (INMARSAT) Council identified G.E. Astro as its prime candidate for building the organization's third-generation satellite system. Contract negotiations are scheduled to be completed by the end of the year. INMARSAT's third-generation satellites will incorporate many state-of-the-art features. They will use four spot-beam antennas to conserve valuable L-band spectrum and will operate at 10 times the power of the second-generation satellites that will enter into service in late 1990 and carry a payload twice the weight of an average civilian communications satellite. With such high power, INMARSAT will introduce a range of new mobile satellite services permitting the use of small, briefcase-size terminals. This will enhance INMARSAT's usefulness for emergency/distress services, ease communications for global travelers, and significantly benefit the development of low-cost communications for the developing world.

After several years of discussions, the INMARSAT Council agreed to establish a second network in the Atlantic Ocean Region, effective September 29, 1990. As a result, the MARECS B-2 satellite has been relocated to 55 degrees West to improve services in the Western Hemisphere.

In January 1989, an extraordinary meeting of the organization's Assembly of Parties adopted amendments to its Convention and Operating Agreement authorizing provision of satellite-based services to vehicles on land. The United States deposited its acceptance of these amendments in September 1990. Once the amendments come into force, INMARSAT will be authorized to offer space segment for land mobile satellite services on a voluntary, non-exclusive basis.

The 1985 amendments to the Convention and Operating Agreement authorizing provision of satellite-based communications to the aeronautical community came into force in October 1989. As a result, several international consortia have been established to offer international services to aeronautical users.

In the United States, the Federal Communications Commission (FCC) decided that the American Mobile Satellite Corporation (AMSC) would be the sole provider of mobile satellite communications services in the L-band of the radio-frequency spectrum. The FCC considered that a single licensee would best manage the scarce spectrum between safety and non-safety services, with priority given to aviation traffic. In a separate decision, the FCC limited the provision of INMARSAT's aeronautical services in the United States solely to international flight. This decision is being contested.

INMARSAT's Council approved a lease request submitted by AMSC for space capacity enabling the U.S. licensee for mobile satellite services to begin before its own satellite system is operational. A similar lease was approved by the Canadian licensee. As a result, INMARSAT repositioned an old MARISAT (maritime communications system) satellite at 106 degrees West to improve coverage for its North American customers.

The United States submitted two formal notifications to INMARSAT pursuant to Article 8 of the Convention with respect to the proposed use of separate space segment facilities for maritime purposes. One involved the interim position reporting and dedicated radio determination service to be used for maritime purposes to be provided by the Geostar Corporation. The other concerned a temporary maritime service provided by the Alpha Lyracom Corporation via the Pan American Satellite System. In both cases, the Council found that the use of such separate space systems was technically compatible with the INMARSAT system and expressed the view to the Assembly of Parties that the services would not cause significant harm to the system. This finding was affirmed by the Sixth Assembly of Parties in January 1989.

At the Seventh Assembly of Parties meeting in Lisbon, October 31 to November 2, 1989, expedited procedures were adopted to facilitate future consultations of separate systems required by Article 8. Under the new procedures, the INMARSAT Council can act on the Assembly's behalf in certain circumstances. In the first application of the new procedures, In March 1990, the Council authorized the Alpha Lyracom Corporation to conduct a 30-day test of two-way data communications between ships in the Caribbean and a U.S. Earth station via the Pan American Satellite System (PanAmSat).

The Seventh Assembly of Parties also agreed that INMARSAT, in consultation with the International Maritime Organization (IMO), should continue studying an appropriate formula to pay for safety/distress-related communications. Maritime tradition is that these services are provided free of charge. Many INMARSAT members, however, consider only the initial shore-to-shore alerts should be free of space segment user charges and that ship-to-shore NAV/MET danger reports and search-and-rescue communications should be at reduced cost. A joint IMO/INMARSAT Meeting of Experts has been set for December 1990 to consider the need for establishing an international funding mechanism to cover the communication costs of the Global Maritime Distress and Safety System which comes into effect in 1992.

International Telecommunications Satellite Organizations

The first of five International Telecommunications Satellite Organizations (INTELSAT) VI-series satellites was successfully launched on October 27, 1989 by an Ariane 4 vehicle. While undergoing in-orbit testing during the rest of the year, the satellite was used on a pre-operational basis to provide international television coverage of major political and social developments in the world. Two additional INTELSAT VI-series satellites were launched in 1990, one on March 14 and the other on June 23. Both of these launches used Titan III vehicles. While the June 23 launch was successful, the March 14 launch left the satellite in a low-Earth orbit. INTELSAT is working with NASA in anticipation of an early 1992 space shuttle mission that would boost the satellite to its operational geostationary orbit. INTELSAT now operates 15 satellites in geostationary orbit.

In July 1989, the 14th INTELSAT Assembly of Parties made a favorable recommendation on the second proposed U.S. international satellite system separate from the INTELSAT system. That system, to be operated by Orion Satellite Corporation, is expected to begin service between North America and Europe in 1992. It will join the Pan American Satellite System, which became operational in 1988, in helping to fulfill the policy objectives in Presidential Determination 85-4. The PanAmSat system, for example, has been instrumental in providing television coverage of world events. Extensive U.S. diplomatic efforts are leading to broader acceptance of the U.S. policy and opening new markets for U.S. commercial participation.

Arms Control and Disarmament Agency

The United States Arms Control and Disarmament Agency (ACDA) was established in 1961 to advise the President on arms control policy. As potential uses of space become technologically more feasible, ACDA's role in the development of policy for and support of arms control in outer space has expanded.

Arms control issues were mentioned in the President's National Space Policy Report of November 2, 1989:

> The United States will consider and, as appropriate, formulate policy positions on arms control measures governing activities in space, and will conclude agreements on such measures only if they are equitable, effectively verifiable, and enhance the security of the United States and our Allies.
>
> The primary forum for negotiations on nuclear and space arms is the Nuclear and Space Talks with the Soviet Union in Geneva. The instructions to the United States Delegation will be consistent with this National Space Policy directive, established legal obligations, and additional guidance by the President. The United States will continue to consult with its Allies on these negotiations and ensure that any resulting agreements enhance the security of the United States and its Allies. Any discussions on arms control relating to activities in space in forums other than NST [Nuclear and Space Talks] must be consistent with, and subordinate to, the foregoing activities and objectives.

Bilateral Discussions on Space Arms Control

In the Defense and Space Talks, a component of the Nuclear and Space Talks with the Soviet Union in Geneva, the United States continues to seek agreement on a cooperative transition to a more stable nuclear balance that would rely increasingly on strategic defenses, should they prove feasible, while preserving U.S options to deploy such strategic defenses when they are ready. To this end, the United States tabled a revised draft Defense and Space Treaty in December 1989. This U.S. draft Treaty preserves the central elements of the agreement reached at the Washington Summit in December 1987 and reflects the outcome of the Wyoming Ministerial in September 1989.

Under this U.S. draft Defense and Space Treaty, the Anti-Ballistic Missile Treaty would remain in force unless and until that Treaty was terminated or superseded as follows:

- Either Party would be permitted to give notice of its intent to deploy strategic ballistic missile defenses beyond the limitations in the Treaty.
- Upon giving such notice, the initiating Party would propose specific measures to implement a cooperative transition to a strategic regime which would include such defenses.
- The Parties would then conduct for a period of three years intensive discussions of strategic stability on such measures.
- If, after this three-year period, either Party decides to deploy strategic ballistic missile defenses in a manner prohibited by the Treaty, then that Party shall give six months' written notice to the other Party of its decision to deploy such defenses.
- In this event, this latter notice requirement shall supersede the notice provision of Article XV of the Treaty.
- Upon expiration of the six-month notification period, the Treaty shall be terminated, unless the Parties agree otherwise.
- In addition, each Party would have supreme national interests withdrawal rights under the U.S. draft Defense and Space Treaty.

The United States has also proposed that each Party may develop, test, and deploy space-based anti-ballistic missile radars and their substitutes without restriction. This proposal is designed to avoid future definition and verification problems and to encourage stabilizing space-based sensors. Additionally, the United States has adopted a testing-in-space initiative which includes the testing-in-space assurance of 1988 and the proposed notification procedures for both sides' testing in space. To demonstrate that the U.S. testing of space-based components of anti-ballistic missile systems based on "other physical principles" capable of substituting for anti-ballistic missile interceptor missiles, which is permitted by the Anti-Ballistic Missile Treaty, does not represent the deployment of such components, the United States is prepared to carry out such permitted testing only from a limited number of designated test satellites.

In April 1990, the United States proposed a free-standing executive agreement, not connected to the Anti-

Ballistic Missile Treaty, on predictability measures in the field of strategic ballistic missile defense. The United States proposed that the following confidence-building measures be implemented on a reciprocal, comparable, and voluntary basis: exchanges of data, meetings of experts, briefings, visits to laboratories, observations of tests, and notifications of anti-ballistic missile test satellites. In addition, at the end of August 1990, the United States proposed a Dual Pilot Implementation of Predictability Measures plan in which the United States and the Soviet Union would each conduct a single cycle of selected predictability measures projects.

Fundamental differences continue to remain between the United States and the Soviet Union on defense and space issues. The Soviet Union seeks to limit the Strategic Defense Initiative. The Soviet Union also favors a protocol to the Anti-Ballistic Missile Treaty, rather than a new Defense and Space Treaty, as a means of dealing with defense and space issues. At the Wyoming Ministerial in September 1989, the Soviet Union excluded linkage between completion of a Strategic Arms Reduction Talks (START) agreement and the achievement of a Defense and Space agreement. The United States welcomed this, believing that the START and Defense and Space treaties must stand on their own merits.

Multilateral Discussions on Space Arms Control

U.S. National Space Policy was stated by President Reagan on July 4, 1982, and reaffirmed in his March 31, 1984, Report to Congress on U.S. Policy and Anti-Satellite Arms Control: "The United States will consider verifiable and equitable arms control measures that would ban or otherwise limit testing and deployment of specific weapon systems, should those measures be compatible with U.S. national security." Guided by these criteria, ACDA continues to deal with multilateral space arms control issues. In FY 1990, ACDA participated in multilateral discussions on outer space mainly in two fora: the United Nations and the Conference on Disarmament in Geneva. However, neither the United States nor any other party has been able to identify any outer space arms control issues appropriate for multilateral negotiations.

Conference on Disarmament

In 1989 and 1990, ACDA participated in discussions on outer space arms control issues in the Conference on Disarmament in Geneva. During both the 1989 and 1990 sessions, the United States again supported the formation of an appropriate specialized *Ad Hoc* Committee to consider issues relevant to space arms control, without a negotiating mandate. The Committee adopted the following program of work for both its 1989 and 1990 sessions:

- Examination and identification of issues relevant to the prevention of an arms race in outer space;
- Existing agreements relevant to the prevention of an arms race in outer space;
- Existing proposals and future initiatives on the prevention of an arms race in outer space.

The United States and its allies participated actively in the work of the *Ad Hoc* Committee, especially in reviewing the arms control aspects and implications of the current outer space legal regime. Several experts, including the U.S. Deputy Defense and Space negotiator, made presentations at meetings of the Committee. While discussion enhanced understanding, issues appropriate for multilateral negotiations were not, in the U.S. view, identified.

United Nations

The First Committee of the U.N. General Assembly, the other major forum where the United States pursues its multilateral arms control objectives for outer space, met from October through December, 1989. During that session, four draft resolutions (U.S.S.R., Canada, China, and Non-Aligned) on outer space were submitted for First Committee consideration. Of these four resolutions, only one, the neutral and non-aligned resolution, was voted upon. The United States voted against the resolution because:

- it took no notice of the more positive international climate that has developed from improved relations between the United States and the Soviet Union;
- it called for negotiations at the Conference on Disarmament on measures to "prevent an arms race in outer space;" and
- it consisted of hostile rhetoric, with elements that

were deliberately aimed at, and critical of, fundamental elements of U.S. policy.

During its 1990 session (October 15-November 16), the First Committee called for a United Nations study on outer space confidence-building measures. Again, the United States objected to this and other proposed studies because of the financial implications. The United States urged members of the First Committee to call for studies only when they are likely to be productive and constructive.

United States Information Agency

During the 20th anniversary of the Apollo lunar landing, the United States Information Agency (USIA) highlighted NASA's historic role in space exploration and increasingly important scientific missions to help protect Earth's environment. The Hubble Space Telescope and prospects for enhanced international cooperation in space exploration, as well as the President's call for the establishment of a manned scientific outpost on the moon, insured continuing overseas interest in USIA's coverage of NASA's many activities. With a wide variety of means at its disposal to publicize NASA initiatives to foreign audiences, ranging from WORLDNET (USIA's international satellite television network) TV interviews, international teleconferences and Voice of America broadcasts to Wireless File articles, and American experts traveling overseas, USIA remains uniquely equipped to continue to tell the world about U.S. progress in space sciences and exploration.

Television

Throughout 1989 and 1990 USIA's Television and Film Service and NASA cooperated very closely. As a result, every major space undertaking received significant worldwide exposure through WORLDNET, USIA's international satellite television network. NASA officials were particularly helpful in explaining U.S. space policy to global audiences in WORLDNET's live, interactive telepress conferences with journalists and scientists overseas.

During the past two years, WORLDNET produced over 15 interactive programs on space-related issues with audiences at U.S. Information Service posts in Europe, Africa, and the Middle East. To celebrate the 20th anniversary of the first moon landing, WORLDNET telecast five programs with the U.S. astronauts. The manager of the National Aero-Space Plane Program talked to audiences in Latin America and Europe. NASA's Exhibits Coordinator spoke about the Paris Air Show to European audiences. A prominent NASA scientist discussed depletion of the ozone layer, while the Assistant Administrator for External Relations took part in a WORLDNET interactive program on the future of U.S. space policy. Other topics included international scientific cooperation in space exploration, the commercial uses of space, and satellite communications.

In addition to the interactives, WORLDNET broadcast every space shuttle launching live via satellite for television viewers around the world. It devoted special attention to the Voyager's dramatic flyby of Neptune, carrying live satellite coverage of the closest encounter, aired live on national television in Australia thanks to the WORLDNET hook-up. NASA's ongoing press conferences during the Voyager mission were also broadcast live.

The new WORLDNET news program, Newsfile, transmitted by satellite five days a week to all geographic areas, carried 20 NASA-related stories as of the end of September 1990.

Voice of America

In English and 42 foreign languages, the Voice of America (VOA) chronicled both the triumphs and setbacks of the 1989-1990 space effort, a period that marked the 20th anniversary of the first moon landing, the return of Voyager 2 photographs from Neptune, the Galileo space probe to Jupiter, and the orbiting of the Cosmic Background Explorer. VOA reported on these events in its regularly scheduled programs including "New Horizons," "Science Notebook," "Science in Our Lives," "Focus/Close-Up," "U.S. Opinion Roundup," "Press Conference, USA," and "Talk to America."

The Voice of America provided live coverage of the 1989 Discovery, Atlantis (Magellan), and Atlantis (Galileo), and 1990 Discovery (Hubble) missions. NASA officials participated in several VOA program efforts. The project to retrieve the Long-Duration Exposure Facility satellite from orbit was also covered through interviews with the space agency's project scientist.

World space activities were monitored and analyzed in interviews with a space policy expert, a Library of Congress aerospace analyst, and a Soviet space program expert. A special live broadcast to mark the 20th anniversary of the Apollo 11 moon landing included commentary from a former astronaut and a former analyst from the National Commission on Space.

Last year three astronauts answered questions phoned in by listeners from around the world on an extended "Talk to America" program, a live call-in show broadcast worldwide.

From 1989 to the end of September 1990, 18 weekly 20-minute "New Horizons" programs dealt with such space issues as a report on the Magellan space probe to Venus, international cooperation in space, and a glimpse at living in the space environment of Space Habitat. Two "New Horizons" broadcast were concerned with space and geology. One examined the moon as the ultimate geological field trip. The other explained the role of satellites in discovering more about Earth's composition.

Using the voices of telescope designers and builders, as well as space agency planners, the VOA broadcast several "New Frontiers" programs about the Hubble Space Telescope. In the days prior to liftoff, VOA featured live reports from its correspondent at the Kennedy Space Center, and then live coverage of the launch. American newspaper editorials about the mission were broadcast on "Opinion Roundup." When it became apparent that Hubble was to be a troubled mission, listeners heard details of the emerging difficulties in newscasts and reports from our science correspondents. VOA also broadcast a "New Horizons" program entitled "The Trouble with Hubble," describing the now-infamous mirror problems. As new developments with the space telescope have become available, VOA has carried the reports and will continue to follow-up with further "New Horizons."

For the Astro 1 astronomy mission, the VOA prepared and broadcast two separate "New Horizons," one in February 1990 and the other in April 1990. Prior to each launch attempt, there were preview reports from science correspondents. When the Space Shuttle Columbia is ready for a fifth launch attempt, VOA will be on-the-air with further live coverage.

The worldwide weekly public affairs program, "Press Conference, USA," brought listeners news of space with the president of the U.S. Space Foundation as guest and, on another program, the author of *Space, Inc.* about the commercialization of space and opportunities for business in space.

In addition to regular science programs, Hubble was the topic on "Focus" after its launch. "Focus," the VOA daily, 20-minute documentary program that is broadcast worldwide, looked at the lasting scientific impact of the mission.

Press and Publications

The Press Division provided news and feature stories on all five space shuttle missions. These included deployment of the unmanned Galileo spacecraft on a six-year voyage to the planet Jupiter and placement of the Hubble Space Telescope in orbit around Earth. USIA's coverage continued as the space telescope, despite a focusing problem, produced dramatic new images of a distant galaxy and an unprecedented look at an exploding star. The Wireless File also carried stories on the unmanned Magellan spacecraft's rendezvous with Venus, which provided scientists with the most detailed images of the cloud-enveloped planet.

USIA covered the launch of a British communications satellite aboard the first U.S. commercial space rocket. The Delta rocket, built by McDonnell Douglas, was also used to launch an Indonesian satellite and a communications satellite for India. Coverage highlights also included a feature on the NASA launch of a scientific research satellite to study Earth's invisible magnetic fields and another on how scientists are studying the atmospheres of other planets to better understand global warming and other aspects of Earth's weather and climate.

USIA magazines dedicated various articles to NASA and space. *America Illustrated* contained articles in Russian on the return of the shuttle, mapping Mars, the 20th anniversary of Apollo 11, and Pioneer 10. *Topic* offered features dealing with the recollections of an astronaut, spinoff benefits from space, the Shuttle Atlantis, a picture story on U.S. programs in space, monitoring Earth from space, and the Hubble Telescope. *Dialogue* prepared articles on charting the galaxies, NASA training aircraft, California's Jet Propulsion Laboratory, tracking by telescope, and a review of communications satellites. *Al Majal* featured Arabic-language stories on weather satellites and Voyager 2 as the superstar of unmanned flight. In addition, a special pamphlet, "On the Frontier: The United States in Space," was produced in multiple language versions.

The Editorial Services Branch regularly produced space-related materials in its special features service, including such topics as the last rendezvous of Voyager 2, the 20th anniversary of Apollo 11, new technology from space research, rescue via space satellites, unexpected uses for satellites, NASA's robot laborers in space, and art in space.

American Participants

Under the American Participant Program, which involves sending prominent Americans overseas to meet with foreign government officials, scientists, scholars, and journalists, five NASA astronauts and one scientist visited foreign countries in 1990. An astronaut navigator visited Portugal to commemorate the 50th anniversary of the Portuguese era of discoveries. NASA's Director of Solar System Exploration visited Brazil to assist in opening ceremonies at the 20th anniversary of the Rio de Janeiro planetarium and participate in a seminar at the Brazilian space agency.

Teleconferences

The outlook for the U.S. space program and the 20th anniversary of the Apollo lunar landing and NASA's scientific efforts to protect the ozone layer and probe solar phenomena formed the core subjects of interest to foreign media, scientists, and scholars. Experts in Egypt, Mexico, Pakistan, and South Africa participated in 10 separate teleconferences with NASA officials, scientists, and current or former astronauts. Five current or former astronauts and a former NASA Administrator gave television and radio audiences their unique perspective on American space initiatives and their contributions to them. A senior NASA scientist demonstrated the space agency's role in mobilizing the worldwide effort to protect the ozone layer. The head researcher for the gamma ray imaging device at the Goddard Space Flight Center spoke of NASA's scientific efforts to understand the impact of solar activity on Earth's atmosphere.

Appendixes

APPENDIX A-1

U.S. Spacecraft Record

(Includes spacecraft from cooperating countries launched by U.S. launch vehicles.)

Calendar Year	Earth Orbit[a]		Earth Escape[a]	
	Success	Failure	Success	Failure
1957	0	1	0	0
1958	5	8	0	4
1959	9	9	1	2
1960	16	12	1	2
1961	35	12	0	2
1962	55	12	4	1
1963	62	11	0	0
1964	69	8	4	0
1965	93	7	4	1
1966	94	12	7	1[b]
1967	78	4	10	0
1968	61	15	3	0
1969	58	1	8	1
1970	36	1	3	0
1971	45	2	8	1
1972	33	2	8	0
1973	23	2	3	0
1974	27	2	1	0
1975	30	4	4	0
1976	33	0	1	0
1977	27	2	2	0
1978	34	2	7	0
1979	18	0	0	0
1980	16	4	0	0
1981	20	1	0	0
1982	21	0	0	0
1983	31	0	0	0
1984	35	3	0	0
1985	37	1	0	0
1986	11	4	0	0
1987	9	1	0	0
1988	16	1	0	0
1989	24	0	2	0
1990 (through Sep. 30)	31	0	0	0
TOTAL	1,192	144	81	15

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[a] The criterion of success or failure used is attainment of Earth orbit or Earth escape rather than judgment of mission success. "Escape" flights include all that were intended to go to at least an altitude equal to lunar distance from the Earth.

[b] This Earth-escape failure did attain Earth orbit and therefore is included in the Earth-orbit success totals.

APPENDIX A-2

World Record of Space Launches Successful in Attaining Earth Orbit or Beyond

(Enumerates launches rather than spacecraft; some launches orbited multiple spacecraft.)

Calendar Year	United States	U.S.S.R.	France	Italy	Japan	People's Republic of China	Australia	United Kingdom	European Space Agency	India	Israel
1957		2									
1958	5	1									
1959	10	3									
1960	16	3									
1961	29	6									
1962	52	20									
1963	38	17									
1964	57	30									
1965	63	48	1								
1966	73	44	1								
1967	57	66	2	1			1				
1968	45	74									
1969	40	70									
1970	28	81	2	1[a]	1	1					
1971	30	83	1	2[a]	2	1		1			
1972	30	74		1	1						
1973	23	86									
1974	22	81		2[a]	1						
1975	27	89	3	1	2	3					
1976	26	99			1	2					
1977	24	98			2						
1978	32	88			3	1					
1979	16	87			2				1		
1980	13	89			2					1	
1981	18	98			3	1			2	1	
1982	18	101			1	1					
1983	22	98			3	1			2	1	
1984	22	97			3	3			4		
1985	17	98			2	1			3		
1986	6	91			2	2			2		
1987	8	95			3	2			2		
1988	12	90			2	4			7		1
1989	17	74			2				7		
TOTAL	895	2,181	10	8	38	23	1	1	30	3	1
1990 (through Sep. 30)	19	56			3	4			3		1
TOTAL	914	2,237	10	8	41	27	1	1	33	3	2

[a] Includes foreign launches of U.S. spacecraft.

APPENDIX A-3

Successful U.S. Launches January 1, 1989–September 30, 1990

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
Feb. 14 GPS (Block IIR) 13A Delta II	Objective: To launch spacecraft into successful orbit. Spacecraft: Not announced.	20,346 20,018 718.0 55.1	First in a series of Block II operational Navstar Global Positioning Satellites (GPS) launched aboard the newest U.S. Air Force expendable launch vehicle, the Delta II. Operational system to be composed of 21 satellites in six orbital planes. In orbit.
Mar. 13 Space Shuttle Discovery (STS-29) 21A	Objective: To deploy the Tracking and Data Relay Satellite-D. Spacecraft: Shuttle orbiter carrying satellite as well as experiments. Orbiter Experiments Autonomous Supporting Instrumentation System (OASIS-I), Space Station Heat Pipe Advanced Radiator Element (SHARE), Air Force Maui Optical Systems (AMOS) Calibration Test, Chromosome and Plant Cell Division in Space Experiment (CHROMEX), IMAX Corporation Camera Experiment (IMAX), Protein Crystal Growth (PCG), and two Shuttle Student Involvement Projects. Weight including spacecraft and experiments: 263,289 lbs.	337 305 91.0 28.5	Twenty-eighth flight of Space Transportation System. Piloted by Michael L. Coats and John E. Blaha. Mission Specialists James P. Bagian, James F. Buchli, and Robert C. Springer. Discovery launched from Kennedy Space Center (KSC), Launch Pad 39B at 9:57 a.m., EST. Satellite successfully deployed and experiments conducted. Shuttle landed at Edwards AFB, CA, Mar. 18 at 9:36 a.m., EST. Mission duration 4 days, 23 hours, 39 minutes.
Mar. 13 TDRS 4 21B	Objective: To deliver Tracking and Data Relay System satellite to geosynchronous orbit. Spacecraft: Three-axis stabilized, momentum-biased configuration with two sun-oriented solar panels attached. TDRS measures 57.17 ft tip to tip of deployed solar panels. TDRS composed of 3 modules: (1) equipment module houses attitude control, electrical power, propulsion, telemetry, tracking, and command subsystems; (2) payload module consists of processing and frequency-generation equipment; (3) antenna module supports dual deployable and fixed antennas, multiple-access array, and remainder of telecommunications hardware. Weight at launch, including IUS upper stage: 43,212 lbs.	35,808 35,768 1,436.1 0.0	Launched from shuttle Discovery Mar. 13. Fourth of a series. Spacecraft replaced partially degraded TDRS 1 at 410 W, and TDRS 1 moved to 790 W serving temporarily as on-orbit spare. Leased by NASA from Continental Telephone Company (CONTEL).
Mar. 24 USA 36 26A Delta	Objective: DOD space test. Spacecraft: Not announced.	499 487 94.5 47.7	USA 36 (also known as Delta 183), experimental missile-hunting satellite equipped with a laser radar, seven video imaging cameras and an infrared imager. In orbit.
May 4 Space Shuttle Atlantis (STS-30) 33A	Objective: To deploy Magellan spacecraft. Spacecraft: Shuttle orbiter carrying satellite as well as experiments. Fluids Experiment Apparatus (FEA), Mesoscale Lightning Experiment (MLE), Air Force Maui Optical Site Calibration (AMOS). Weight, including Magellan and experiments: 260,878 lbs.	331 297 90.8 28.9	Twenty-ninth flight of Space Transportation System. Piloted by David M. Walker and Ronald J. Grabe. Mission specialists Norman E. Thagard, Mary L. Cleave, and Mark C. Lee. Atlantis successfully launched at 2:46:59 p.m., EDT after several countdown holds. Satellite successfully deployed and experiments conducted. Shuttle landed May 8 at 3:43:37.89 p.m., EDT at Edwards AFB, CA on runway 22. Mission duration of 4 days, 57 minutes.

Successful U.S. Launches January 1, 1989–September 30, 1990

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
May 4 Magellan 33B	Objective: To place satellite carrying radar sensor into orbit around Venus to obtain data on planetary surface. Spacecraft: Three-axis stabilized, length, 6.4 m, and solar panels with span of 9.2 m. Composed of satellite structure, thermal control, power, attitude control, propulsion, command data and storage, and telecommunications subsystems. Magellan and IUS booster weight: 45,748 lbs.	Trans-Venus trajectory	Magellan successfully launched from shuttle Atlantis on revolution 5, 6 hours, 14 minutes after launch. Spacecraft placed on planned trajectory for rendezvous and orbit with Venus on Aug. 10, 1990.
May 10 USA 37 35A	Objective: Not announced. Spacecraft: Not announced.	Not announced.	In orbit.
Jun. 10 GPS (Block IIR) 44A Delta II	Objective: To launch spacecraft into successful orbit. Spacecraft: Not announced.	20,401 19,962 718.0 54.7	Second in a series of Block II operational Navstar Global Positioning Satellites (GPS) launched by Delta II. Completed system will have 21 operational and three spare satellites. Also known as USA 38. In orbit.
Jun. 14 USA 39 46A Titan IV	Objective: To launch upgraded Defense Support Program satellite (DSP-1). Spacecraft: Not announced.	Not announced.	First launch of Titan IV expendable launch vehicle. In orbit.
Aug. 8 Space Shuttle Columbia (STS-28) 61A	Objective: DOD mission payload/cargo not announced. Spacecraft: Shuttle orbiter carrying classified DOD payload/cargo. Six Detailed Supplementary Objectives (DSOs) were completed, including those associated with the Extended Duration Orbiter (EDO) Medical Program. Weight: Not announced.	317 314 90.5 56.9	Thirtieth flight of Space Transportation System. Piloted by Brewster Shaw and Richard Richards. Mission specialists James Adamson, David Leestma, and Mark Brown. Shuttle lift-off at 8:37 a.m., EDT from KSC. Landing at Edwards AFB, CA, 9:37:53 EDT, Aug. 13. Mission duration: 5 days, 1 hour.
Aug. 8 USA 40 61B	Objective: Not announced. Spacecraft: Not announced.	Not announced.	In orbit.
Aug. 8 USA 41 61C	Objective: Not announced.	Not announced.	In orbit.
Aug. 18 GPS (Block IIR) 64A Delta II	Objective: To launch satellite into successful orbit. Spacecraft: Not announced.	20,252 20,111 718.0 55.0	Third in a series of 21 Block II operational Navstar Global Positioning Satellites (GPS) launched aboard a Delta II expendable launch vehicle. Also known as USA 42. In orbit.
Sep. 4 USA 43 69A Titan III	Objective: Not announced. Spacecraft: Not announced.	Not announced.	In orbit.
USA 44 69B	Objective: Not announced. Spacecraft: Not announced.	Not announced.	In orbit.

APPENDIX A-3—*Continued*

Successful U.S. Launches
January 1, 1989–September 30, 1990

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
Sep. 6 USA 45 72A Titan II	Objective: Not announced. Spacecraft: Not announced.	Not announced.	In orbit.
Sep. 25 FltSatCom F-8 77A Atlas Centaur 68	Objective: To launch Navy communications satellite into geosynchronous transfer orbit. Spacecraft: Body is 8 feet in diameter and 22.8 feet high. Parabolic antenna is 16 feet in diameter with 80-inch solid center surrounded by wire mesh screen. Once in orbit, the folded screen is deployed. 13.5-foot helical receiving antenna, 13 inches in diameter at base, mounted outside the edge of the transmit antenna dish. Weight, going into orbit, with apogee kick motor: 5,100 lbs.	35,799 35,776 1,436.2 4.8	Successfully launched by NASA/industry team for Dept. of Navy. Last in NASA inventory of Atlas Centaur rockets. Sixth, and last in a series of geosynchronous satellites part of a worldwide Navy, Air Force, and DOD communications system. Also known as USA 46. In orbit.
Oct. 18 Space Shuttle Atlantis (STS-34) 84A	Objective: To successfully launch Galileo spacecraft toward rendezvous with Jupiter. Spacecraft: Shuttle orbiter carrying spacecraft with Inertial Upper Stage (IUS) booster with additional experiments. Shuttle Solar Backscatter Ultra-Violet Instrument (SSBUV), Growth Hormone Concentration and Distribution in Plants (GHCD), Polymer Morphology Exp. (PM), Mesoscale Lightning Exp. (MLE), Sensor Tech. Exp. (STEX), Air Force Maui Optical Site (AMOS), IMAX, and one Shuttle Student Involvement Project. Weight, including space probe and experiments (not including shuttle): 46,009 lbs.	160 160 90 34.30	Thirty-first flight of Space Transportation System. Donald E. Williams, commander, Michael J. McCulley, pilot. Mission Specialists Shannon W. Lucid, Franklin R. Chang-Diaz, and Ellen S. Baker. Lift-off at 12:53:40 p.m., EDT from KSC. Landing at Edwards AFB, CA runway 23 after 80 orbits at 12:33 p.m., EDT, Oct. 23. Spacecraft deployed successfully and experiments conducted. Mission duration 4 days, 23 hours, 39 minutes.
Oct. 18 Galileo 84B	Objective: To launch spacecraft into successful trajectory toward Jupiter to allow close-range studies over a period of almost two years. Spacecraft: Composed of three segments. The first, the probe, includes a heat shield, a 2.5-m parachute, six instruments together with control and data system, a radio-relay transmitter, and other supporting equipment. The probe weighs 335 kg (including 28 kg of scientific instruments). The second segment is the spinning main section which includes the propulsion module, communications antennas, main computers, and most support systems. The third segment carries field and particle instruments. Orbiter (second and third segments) weighs 2,668 kg (including 103 kg of science instruments and 935 kg of propellant).	Trans-Jupiter trajectory	Spacecraft successfully launched from shuttle Atlantis. Planned arrival at Jupiter December 1995.
Oct. 21 GPS (Block IIR) 85A Delta II	Objective: To launch satellite into successful orbit. Spacecraft: Not announced.	20,283 20,079 717.9 54.7	Fourth in series of Block II operational Navstar Global Positioning Satellites (GPS). Also known as USA 47. In orbit.
Nov. 18 COBE 89A Delta 5920	Objective: To successfully launch satellite to enable it to measure diffuse infrared radiation (cosmic background). Spacecraft: Rotating three-axis stabilized; length 7.2 m (stowed) and 27.5 m with solar panels deployed in orbit. Carries three instruments, Differential Microwave Radiometer (DMR), Far Infrared Absolute Spectrophotometer (FIRAS), and Diffuse Infrared Background Experiment (DIRBE). Weight: 2,206 kg.	895 886 102.8 99.0	Cosmic Background Explorer (COBE) successfully launched using the 184th and last NASA-owned Delta. COBE is the 65th Explorer class mission. Launched from Vandenberg AFB, CA. Mission life: one year planned, primary mission; one year planned extended mission. In orbit. Returning data.

Successful U.S. Launches
January 1, 1989–September 30, 1990

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
Nov. 23 Space Shuttle Discovery (STS-33) 90A	Objective: Not announced. Spacecraft: Shuttle orbiter carrying unannounced DOD satellite. Weight: Not available.	Not announced.	Thirty-second flight of Space Transportation System. Discovery launched from KSC, Nov. 22 at 7:23 p.m., EST. Crew composed of Frederick D. Gregory, commander, John E. Blaha, pilot. Mission specialists Kathryn C. Thornton, F. Story Musgrave, Manely L. "Sonny" Carter. Landed Edwards AFB, CA runway 4 at 7:31 p.m., EST, Nov. 27. Mission duration: 5 days, 7 min.
Nov. 23 DOD 90B	Objective: Not announced. Spacecraft: Not announced.	Not announced.	
Dec. 11 GPS (Block IIR) 97A Delta II	Objective: To launch satellite into successful orbit. Spacecraft: Not announced.	20,359 20,010 718.1 54.9	Fifth in a series of Block II operational Global Positioning Satellites (GPS) launched by U.S. Air Force Delta II. Also known as USA 49. In orbit.
Jan. 1, 1990 Skynet 4A 1A Titan III	Objective: To successfully launch satellite. Spacecraft: Not announced. Weight: 3,320 lbs.	35,782 33,685 1,382.5 3.4	Commercial launch by Martin Marietta for British Ministry of Defence. In orbit.
Jan. 1 JCSAT 2 1B	Objective: To successfully launch satellite. Spacecraft: Not announced. Weight: 14,700 lbs.	7,191 821 180.1 0.3	Second satellite in dual payload Titan 3 launch. Satellite owned by Japanese Communications Satellite Co. In orbit.
Jan. 9 Space Shuttle Columbia (STS-32) 2A	Objective: To launch Syncom IV-5, retrieve Long Duration Exposure Facility (LDEF), and conduct scientific and medical experiments while in weightless environment. Spacecraft: Shuttle orbiter carrying satellite as well as following middeck experiments: American Flight Echocardiograph (AFE), Characterization of Neurospora Circadian Rhythms (CNCR), Fluid Experiment Apparatus (FEA), Latitude/Longitude Locator (L3), Protein Crystal Growth (PCG), and IMAX camera. Additionally Mesoscale Lightning Experiment (MLE), and Air Force Maui Optical Site Calibration Test (AMOS). Weight of orbiter and cargo at SRB ignition: 256,670 lbs.	342 316 90.8 28.4	Thirty-third flight of Space Transportation System. Piloted by Daniel C. Brandenstein and James D. Wetherbee. Mission specialists Bonnie J. Dunbar, Marsha S. Ivins, and G. David Low. Columbia lifted off from KSC, pad 39-A at 7:35 a.m., EST. After successfully deploying Syncom IV-5 Columbia crew successfully captured LDEF Jan. 11, at 10:16 a.m., EST. After detailed photographic survey, satellite berthed in cargo bay 4 1/2 hours later. LDEF had been launched by STS-41C in April 1984. Shuttle landed at Edwards Air Force Base, CA, Jan. 20 at 1:35 a.m., PST. Landing delayed one day because of ground fog at landing site. Mission duration: 10 days, 21 hrs, making this the longest shuttle flight to date.
Jan. 9 Syncom IV-5 (Leasat-5) 2B	Objective: To launch satellite into transfer orbit. Spacecraft: Cylindrical, telescoping satellite. Dimensions: 15 feet long, 13 feet in diameter. Total weight in cargo bay: 17,000 lbs., weight of satellite in orbit: 3,060 lbs.	36,363 34,858 1,427.1 1.4	Successfully launched from Columbia for U.S. Navy. Replacement for FltSatCom spacecraft. Fourth operational satellite in the Leasat system. In orbit.
Jan. 24 USA-50 8A	Development of spaceflight techniques and technology. Spacecraft: Not announced.	20,088 718.0 54.6	Global Positioning Satellite (GPS). Sixth navigation satellite in the series. In orbit.

APPENDIX A-3—*Continued*

Successful U.S. Launches
January 1, 1989–September 30, 1990

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
Feb. 14 USA-51 15A Delta II	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	549 532 95.3 43	Low-power atmospheric compensation experiment (LACE) satellite. Part of the Strategic Defense Initiative (SDI) program. In orbit.
Feb. 14 USA-52 15B Objective:	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced. 20,275	470 464 93.8 43.1	Relay Mirror Experiment (RME) satellite. Part of the Strategic Defense Initiative (SDI) program testing. In orbit.
Feb. 28 Space Shuttle Atlantis (STS-36) 19A	Objective: To successfully launch DOD payload. Spacecraft: Shuttle orbiter carrying unannounced satellite. Weight: Not available.	264 248 89.4 61.9	Thirty-fourth flight of Space Transportation System. Piloted by John O. Creighton and John H. Casper. Mission specialists David C. Hilmers, Richard M. Mullane, and Pierre J. Thout. Atlantis launched from Pad 39-A, at KSC, 2:50 a.m., EST. Shuttle landed at Edwards AFB, CA, Mar. 4, at 10:08 a.m., PST. Mission duration 4 days, 10 hrs., 19 min.
Feb. 28 USA-53 19B	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not announced.	Classified payload launched by shuttle Atlantis crew. In orbit.
Mar. 14 Intelsat 6 F-3 21A Titan III	Objective: To successfully launch satellite into geosynchronous orbit. Spacecraft: Launch configuration is 17.5 feet (5.3 m) tall, with diameter of 12 feet (3.6 m). Five antennas, and two cylindrical solar arrays. In orbit telescoping spacecraft is nearly 39 feet (11.7 m) tall. Weight at launch, including apogee kick stage: 27,425 lbs (12,466 kg).	338 166 89.3 28.6	Launch vehicle malfunction, stranding satellite in useless orbit. Intelsat may request NASA to use shuttle in rescue attempt. In orbit.
Mar. 26 USA-54 25A Delta II	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	20,207 20,059 716.0 55.1	Global Positioning Satellite (GPS). Seventh navigation satellite in the series. In orbit.
Apr. 5 PEGSAT 28A Pegasus	Objective: To successfully launch satellite, and test new launch delivery system. Spacecraft: Two barium canisters, 50 inches (127 cm) high and 42 inches (106 cm) wide. Weight: 272 lbs.	682 500 96.4 94.1	NASA-built small payload, to obtain environmental measurements of Pegasus launch vehicle for DARPA, deploy Navy satellite, and conduct two NASA scientific chemical-release experiments over north-central Canada.
Apr. 5 USA-55 28B	Objective: To successfully launch small experimental Navy satellite. Spacecraft: Polygonal sphere. Weight: 150 lbs.	673 498 96.3 94.1	Navy-designed Small Experimental Communications Satellite (SECS) deployed from Pegsat. In orbit.
Apr. 11 USA-56 31A Atlas E	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not announced.	In orbit. First of triple payload launch.
Apr. 11 USA-57 31B	Objective: Development of spaceflight techniques and technology. Spaceflight: Not announced.	Not announced.	In orbit. Second of triple payload launch.

Successful U.S. Launches January 1, 1989–September 30, 1990

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
Apr. 11 USA-58 31C	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not announced.	In orbit. Third of triple payload launch.
Apr. 13 PALAPA-B2R 34A Delta	Objective: To successfully launch spacecraft into geosynchronous orbit. Spacecraft: Not available.	37,785 35,717 1,485.1 0.4	Indonesian communications satellite launched by United States. In orbit.
Apr. 24 Space Shuttle Discovery (STS-31) 37A	Objective: To successfully launch Hubble Space Telescope and conduct scientific and medical experiments while in weightless environment. Spacecraft: Shuttle orbiter carrying satellite as well as following experiments: Ascent Particle Monitor (APM), IMAX camera, Investigation into Polymer Membrane Processing (IPMP), Protein Crystal Growth (PCG), Radiation Monitoring Experiment (RME), Ion Arc (Student Experiment), and Air Force Maui Optical Site Calibration Test (AMOS). Weight of orbiter and cargo at main engine cutoff: 259,229 lbs.	619 613 96.8 28.4	Thirty-fifth flight of Space Transportation System. Piloted by Loren J. Shriver and Charles F. Bolden, Jr. Mission specialists Steven A. Hawley, Bruce McCandless II, and Dr. Kathryn D. Sullivan. Discovery launched from KSC, Pad 39-B, 8:33 a.m., EDT. Landed at Edwards AFB, CA, Apr. 29, at 6:49 a.m., PDT. Mission duration 5 days, 1 hr, 16 min.
Apr. 25 Hubble Space Telescope 37B	Objective: To successfully perform a variety of astronomical observations as a long-term (15-year) international observatory with many different scientific goals and observational modes. Spacecraft: Cylindrical body made up of three major elements: the support systems module, the optical telescope assembly, and the scientific instruments. Electrical power provided by two solar arrays containing 48,000 solar cells. Optical telescope assembly contains two mirrors, a 94-inch primary mirror located near the center of the HST. The 13-inch secondary mirror is located 16 feet in front of the primary mirror. Two mirrors must remain in precise alignment for the images to be in focus. HST's scientific instruments are the Wide Field/Planetary Camera, the Goddard High Resolution Spectrograph, the Faint Object Spectrograph, and the High Speed Photometer. Weight at launch approximately 25,000 lbs (11,355.4 kg).	620 611 96.8 28.4	Successfully deployed by shuttle orbiter Discovery. Faint Object Camera (FOC) became first scientific instrument to complete its orbital verification activities on Jun. 6. First images taken by Wide Field/Planetary Camera released May. 20. Spherical aberration in the HST optical system announced publicly Jun. 27. Problem traced to a spacing error in the reflective null corrector, an optical reference device used in the manufacture of the primary mirror. The Wide Field/Planetary Camera was directed to study developing storm on Saturn; images expected to be three to 10 times better than those from Earth-based telescopes.
May 9 M-1 43A Scout	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	783 641 98.6 89.8	First of dual Lightsat launch. In orbit.
May 9 M-2 43B	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	782 640 98.6 89.8	Second in dual Lightsat launch. In orbit.
Jun. 1 ROSAT 49A Delta II	Objective: To conduct an all-sky survey for six months, using the imaging telescopes to measure positions of x-ray and extreme, ultraviolet (XUV) sources, while obtaining fluxes and spectral information. Spacecraft: Square-shaped central body containing scientific instruments, with three solar arrays. Launch configuration dimensions 4.5 m x 2.2 m x 2.4 m. Instrumentation includes most powerful x-ray telescope ever built, with secondary telescope a Wide Field Camera. Launch weight: 2,424 kg.	588 567 96.1 52.9	Roentgen Satellite (ROSAT) international cooperative satellite successfully launched from the Cape Canaveral Air Force Station, FL. This joint mission with the Federal Republic of Germany and the United Kingdom has a two-phase schedule: (a) a six-month survey to be conducted by German scientists and (b) a 12-month pointed phase, where telescopes are pointed at pre-selected individual x-ray sources. Spacecraft still in orbit and returning data.

APPENDIX A-3—*Continued*

Successful U.S. Launches
January 1, 1989–September 30, 1990

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
Jun. 8 USA-59 50A Titan IV	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not announced.	One of four satellites launched by single booster. In orbit.
Jun. 8 USA-60 50B	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not announced.	Second of four satellite launch. In orbit.
Jun. 8 USA-61 50C	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not announced.	Third of four satellite launch. In orbit.
Jun. 8 USA-62 50D	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not announced.	Fourth of four satellite launch. In orbit.
Jun. 12 INSAT 1D 51A Delta	Objective: To successfully launch communications satellite to geosynchronous orbit. Spacecraft: Same basic configuration as INSAT 1B launched by shuttle in 1983.	35,974 35,767 1,440.0 0.2	Launched by United States for India to replace INSAT 1B. Completes INSAT 1 series. In orbit.
Jun. 23 Intelsat 6 F-4 56A Titan III	Objective: To launch satellite into geosynchronous orbit. Spacecraft: Same as Intelsat 6 launched Mar. 14.	35,791 35,785 1,436.2 0.0	Launched by Martin Marietta for Intelsat. Third in a series of five Intelsat 6 satellites. Operational in early Sept. Spacecraft in orbit located at 332.50 East.
Jul. 25 CRRES 65A Atlas 1/Centaur 69	Objective: To successfully launch satellite into a highly elliptical geosynchronous transfer orbit to enable performance of active chemical release experiments in the ionosphere and magnetosphere. Spacecraft: Octagonal satellite with two attached solar arrays and deployable magnetometer boom and 24 releasable canisters. Weight: 3,842 lbs.	33,612 335 591.9 18.2	Combined Release and Radiation Effects Satellite, a joint NASA/USAF payload, launched atop the first commercial Atlas launch vehicle. First canister released over the South Pacific Sept. 10. In orbit.
Aug. 2 USA-63 68A Delta II	Objective: To place satellite into successful orbit from which Navy objectives can be met. Spacecraft: Not announced.	20,665 19,931 722.7 54.7	Global Positioning Satellite (GPS). Eighth navigation satellite. In orbit.
Aug. 18 BSB-R2 74A Delta	Objective: To successfully launch satellite. Spacecraft: Not available.	35,859 35,565 1,432.2 0.3	Launched for British Satellite Broadcasting. In orbit.

APPENDIX B-1

U.S.-Launched Applications Satellites, 1984–1990

Date	Name	Launch Vehicle	Remarks
		COMMUNICATIONS	
Feb. 3, 1984	Westar-6	Space Shuttle, PAM-D	Launched for Western Union, PAM-D failed to fire properly, satellite retrieved by Shuttle, and returned to earth for refurbishment.
Feb. 6, 1984	Palapa-B2	Space Shuttle, PAM-D	Launched for Indonesia, booster motor failed, satellite retrieved and returned to Earth by Shuttle.
Mar. 1, 1984	Uosat-2	Delta 3920	Secondary payload with Landsat-5, for amateur radio communications.
June 9, 1984	Intelsat V F-9	Atlas-Centaur	Seventh in series, launch vehicle failure, satellite reentered Oct. 24.
Aug. 31, 1984	SBS-4	Space Shuttle, PAM-D	Launched for Satellite Business Systems, Inc.
Aug. 31, 1984	Syncom IV-2	Space Shuttle	Launched for Hughes Communications, Inc.
Sept. 1, 1984	Telstar-3C	Space Shuttle, PAM-D	Launched for American Telephone and Telegraph Co.
Sept. 21, 1984	Galaxy-3	Delta 3920/PAM-D	Third in series, launched for Hughes Communications, Inc.
Nov. 9, 1984	Anik-D2	Space Shuttle, PAM-D	Launched for Telsat Canada.
Nov. 10, 1984	Syncom IV-1	Space Shuttle	Launched for Hughes Communications, Inc.
Nov. 14, 1984	NATO IIID	Delta 3914	NATO defense-related communications satellite.
Mar. 22, 1985	Intelsat VA F-10	Atlas-Centaur	First in series of six improved satellites.
Apr. 12, 1985	Telesat-I	Space Shuttle	Launched for Telsat Canada.
Apr. 13, 1985	Syncom IV-3	Space Shuttle	Launched for US Navy.
June 17, 1985	MORELOS-A	Space Shuttle	Launched for Mexico.
June 18, 1985	Arabsat-1B	Space Shuttle	Launched for Arab Satellite Communication Organization (ASCO).
June 19, 1985	Telstar-3D	Space Shuttle	Launched for the American Telephone and Telegraph Company (AT&T).
June 30, 1985	Intelsat VA F-11	Atlas-Centaur	Second in series of improved satellites launched for INTELSAT.
Aug. 27, 1985	AUSSAT-1	Space Shuttle	Launched for Australia's National Satellite Company.
Aug. 27, 1985	ASC-1	Space Shuttle	Launched for American Satellite Company.
Aug. 29, 1985	Syncom IV-4	Space Shuttle	Launched for US Navy.
Sep. 29, 1985	Intelsat VA F-12	Atlas-Centaur	Launched for INTELSAT.
Nov. 27, 1985	MORELOS-B	Space Shuttle	Launched for Mexico.
Nov. 27, 1985	AUSSAT-2	Space Shuttle	Second satellite launched for Australia's National Satellite Company.
Nov. 28, 1985	RCA Satcom K-2	Space Shuttle	Launched for RCA American Communications, Inc.
Jan. 12, 1986	RCA Satcom K-1	Space Shuttle	Launched for RCA American Communications, Inc.
Dec. 5, 1986	Fltsatcom 7	Atlas-Centaur	Launched for DoD.
Mar. 20, 1987	Palapa B-2P	Delta 182	Indonesia domestic communications.
Sep. 25, 1989	FltSatCom F-8	Atlas/Centaur	Sixth, and last in series of geosynchronous satellites, for U.S. Navy.
Jan. 1, 1990	Skynet 4A	Titan III	Launched for British Ministry of Defence.
Jan. 1, 1990	JCSAT 2	Titan III	Second of dual Titan III launch, for Japanese Communications Satellite Co.
Jan. 9, 1990	Syncom IV-5	Space Shuttle	Leasat 5, fourth in series of satellites, for U.S. Navy.
Mar. 14, 1990	Intelsat 6 F-3	Titan III	Launched for INTELSAT.
Apr. 13, 1990	Palapa-B2R	Delta	Launched for Indonesia.
Jun. 23, 1990	Intelsat 6 F-4	Titan III	Launched for INTELSAT.
Aug. 18, 1990	BSB-2R	Delta	Launched for British Satellite Broadcasting.

Appendix B-1—*Continued*

U.S.-Launched Applications Satellites, 1984–1990

Date	Name	Launch Vehicle	Remarks
			WEATHER OBSERVATION[a]
Dec. 12, 1984	NOAA-9	Atlas E	Launched for NOAA, to replace NOAA-7.
Sep. 17, 1986	NOAA-10	Atlas E	Launched for NOAA.
Feb. 26, 1987	GOES 7	Delta 179	Launched for NOAA, operational as GOES-East.
June 20, 1987	DMSP F-8	Atlas E	Third in block 5D-2 series, DoD meteorological satellite.
Feb. 2, 1988	DMSP F-9	Atlas E	DoD meteorological satellite.
Sep. 24, 1988	NOAA-11	Atlas E	Launched for NOAA, to replace NOAA-9.
			EARTH OBSERVATION
Mar. 1, 1984	Landsat-5	Delta 3920	Fifth experimental earth resources satellite, to replace ailing Landsat-4.
			GEODESY
Mar. 13, 1985	GEOSAT	Atlas E	Measure ocean surface height.
			NAVIGATION[a]
Feb. 5, 1984	IRT	Space Shuttle	Balloon to test Shuttle rendezvous radar.
June 13, 1984	Navstar-9	Atlas E	Global Positioning System satellite.
Sept. 8, 1984	Navstar-10	Atlas E	Global Positioning System satellite.
Oct. 12. 1984	Nova-3	Scout	Second of improved Transit system satellites, for DoD.
Aug. 3, 1985	Oscar 24	Scout	Part of Navy Transit System.
Aug. 3, 1985	Oscar 30	Scout	Part of Navy Transit System.
Oct. 9, 1985	Navstar-11	Atlas E	Global Positioning System satellite.
Apr. 25, 1988	SOOS-3	Scout	Dual satellites, part of Navy navigation system.
Jun. 16, 1988	NOVA-2	Scout	Third of improved Transit system satellites, for DoD.
Aug. 25, 1988	SOOS-4	Scout	Dual satellites, part of Navy navigation system.
Feb. 14, 1989	GPS-1 (Block IIR)	Delta II	Global Positioning System satellite.
June 10, 1989	GPS-2 (Block IIR)	Delta II	Global Positioning System satellite.
Aug. 18, 1989	GPS-3 (Block IIR)	Delta II	Global Positioning System satellite.
Oct. 21, 1989	GPS-4 (Block IIR)	Delta II	Global Positioning System satellite.
Dec. 11, 1989	GPS-5 (Block IIR)	Delta II	Global Positioning System satellite.
Jan. 24, 1990	GPS-6 (Block IIR)	Delta II	Global Positioning System satellite.
Mar. 26, 1990	GPS-7 (Block IIR)	Delta II	Global Positioning System satellite.
Aug. 2, 1990	GPS-8 (Block IIR)	Delta II	Global Positioning System satellite.

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[a] Does not include Department of Defense weather satellites that are not individually identified by launch.

APPENDIX B-2

U.S.-Launched Scientific Satellites, 1984–1990

Date	Name	Launch Vehicle	Remarks
Apr. 6, 1984	Long Duration Exposure Facility (LDEF-1)	Space Shuttle	Scientific experiments designed for retrieval from space by Shuttle.
Aug. 16, 1984	Charge Composition Explorer (CCE)	Delta 3924	Measurement of Earth's magnetosphere, one of three satellites composing Active Magnetosphere Particle Tracer Explorers Mission (AMPTE).
Aug. 16, 1984	Ion Release Module (IRM)	Delta 3924	Second of three satellites of AMPTE Mission, launched by same vehicle.
Aug. 16, 1984	United Kingdom Satellite (UKS)	Delta 3924	Third of three satellites of AMPTE Mission, launched by same vehicle.
Oct. 5, 1984	Earth Radiation Budget Satellite (ERBS)	Space Shuttle	First of three satellites in Earth Radiation Budget Experiment Research Program. NOAA-9 and NOAA-G carrying other instruments in Program.
Apr. 29, 1985	NUSAT-1	Space Shuttle	Northern Utah Satellite (air traffic control radar system calibrator).
June 20, 1985	Spartan-1	Space Shuttle	Reusable free-flying platform.
July 29, 1985	Plasma Diagnostic Package (PDP)	Space Shuttle	Reusable experimental platform.
Oct. 30, 1985	GLOMR	Space Shuttle	Global Low Orbiting Message Relay satellite.
Nov. 14, 1986	Polar Bear	Scout	Experiments to study radio interference caused by Aurora Borealis, for DoD.
Mar. 25, 1988	San Marco D/L	Scout	International satellite to study earth's lower atmosphere.
Nov. 18, 1989	COBE	Delta	Measurement of cosmic background.
Feb. 14, 1990	LACE	Delta II	Low-powered atmospheric compensation experiment, for DOD.
Feb. 14, 1990	RME	Delta II	Second payload, relay mirror experiment satellite, for DOD.
Apr. 5, 1990	PEGSAT	Pegasus	Chemical release experiment satellite for NASA and DOD.
Apr. 25, 1990	Hubble Space Telescope	Space Shuttle	Long-term astronomical observations.
June 1, 1990	ROSAT	Delta II	Measurement of x-ray and extreme ultraviolet sources.
Jul. 25, 1990	CRRES	Atlas/Centaur	Chemical release experiment.

U.S.-Launched Space Probes, 1975–1990

Date	Name	Launch Vehicle	Remarks
Aug. 20, 1975	Viking 1	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Chryse, Sept. 6, 1976, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of atmosphere.
Sept. 9, 1975	Viking 2	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Utopia, July 20, 1976, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of the atmosphere.
Jan. 15, 1976	Helios 2	Titan IIIE-Centaur	Flew in highly elliptical orbit to within 41 million km of Sun, measuring solar wind, corona, electrons, and cosmic rays. Payload had same West German and U.S. experiments as Helios 1 plus cosmic-ray burst detector.
Aug. 20, 1977	Voyager 2	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Swung around Jupiter in July 1979, arrived Saturn in 1981, going on to Uranus by 1986, Neptune by 1989.
Sep. 5, 1977	Voyager 1	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Passing Voyager 2 on the way, swung around Jupiter in Mar. 1979, arrived at Saturn in Nov. 1980, headed for outer solar system.
May 20, 1978	Pioneer Venus 1	Atlas-Centaur	Venus orbiter; achieved Venus orbit Dec. 4, returning imagery and data.
Aug. 8, 1978	Pioneer Venus 2	Atlas-Centaur	Carried 1 large, 3 small probes plus spacecraft bus; all descended through Venus atmosphere Dec. 9, returned data.
May 4, 1989	Magellan	Space Shuttle	Venus orbiter, achieved Venus orbit Aug. 10, 1990, returning radar image of surface.
Oct. 18, 1989	Galileo	Space Shuttle	Planetary exploration spacecraft, composed of probe to enter Jupiter's atmosphere and orbiter to return scientific data.

Appendix C

U.S. and Soviet Manned Spaceflights, 1961–1990

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Vostok 1	Apr. 12, 1961	Yuriy A. Gagarin	0 : 1 : 48	First manned flight.
Mercury-Redstone 3	May 5, 1961	Alan B. Shepard, Jr.	0 : 0 : 15	First U.S. flight; suborbital.
Mercury-Redstone 4	July 21, 1961	Virgil I. Grissom	0 : 0 : 16	Suborbital; capsule sank after landing; astronaut safe.
Vostok 2	Aug. 6, 1961	German S. Titov	1 : 1 : 18	First flight exceeding 24 h.
Mercury-Atlas 6	Feb. 20, 1962	John H. Glenn, Jr.	0 : 4 : 55	First American to orbit.
Mercury-Atlas 7	May 24, 1962	M. Scott Carpenter	0 : 4 : 56	Landed 400 km beyond target.
Vostok 3	Aug. 11, 1962	Andriyan G. Nikolayev	3 : 22 : 25	First dual mission (with Vostok 4).
Vostok 4	Aug. 12, 1962	Pavel R. Popovich	2 : 22 : 59	Came within 6 km of Vostok 3.
Mercury-Atlas 8	Oct. 3, 1962	Walter M. Schirra, Jr.	0 : 9 : 13	Landed 8 km from target.
Mercury-Atlas 9	May 15, 1963	L. Gordon Cooper, Jr.	1 : 10 : 20	First U.S. flight exceeding 24 h.
Vostok 5	June 14, 1963	Valeriy F. Bykovskiy	4 : 23 : 6	Second dual mission (with Vostok 6).
Vostok 6	June 16, 1963	Valentina V. Tereshkova	2 : 22 : 50	First woman in space; within 5 km of Vostok 5.
Voskhod 1	Oct. 12, 1964	Vladimir M. Komarov Konstantin P. Feoktistov Boris G. Yegorov	1 : 0 : 17	First 3-man crew.
Voskhod 2	Mar. 18, 1965	Pavel I. Belyayev Aleksey A. Leonov	1 : 2 : 2	First extravehicular activity (Leonov, 10 min).
Gemini 3	Mar. 23, 1965	Virgil I. Grissom John W. Young	0 : 4 : 53	First U.S. 2-man flight; first manual maneuvers in orbit.
Gemini 4	June 3, 1965	James A. McDivitt Edward H. White II	4 : 1 : 56	21-min extravehicular activity (White).
Gemini 5	Aug. 21, 1965	L. Gordon Cooper, Jr. Charles Conrad, Jr.	7 : 22 : 55	Longest-duration manned flight to date.
Gemini 7	Dec. 4, 1965	Frank Borman James A. Lovell, Jr.	13 : 18 : 35	Longest-duration manned flight to date.
Gemini 6-A	Dec. 15, 1965	Walter M. Schirra, Jr. Thomas P. Stafford	1 : 1 : 51	Rendezvous within 30 cm of Gemini 7.
Gemini 8	Mar. 16, 1966	Neil A. Armstrong David R. Scott	0 : 10 : 41	First docking of 2 orbiting spacecraft (Gemini 8 with Agena target rocket).
Gemini 9-A	June 3, 1966	Thomas P. Stafford Eugene A. Cernan	3 : 0 : 21	Extravehicular activity; rendezvous.
Gemini 10	July 18, 1966	John W. Young Michael Collins	2 : 22 : 47	First dual rendezvous (Gemini 10 with Agena 10, then Agena 8).
Gemini 11	Sept. 12, 1966	Charles Conrad, Jr. Richard F. Gordon, Jr.	2 : 23 : 17	First initial-orbit docking; first tethered flight; highest Earth-orbit altitude (1,372 km).
Gemini 12	Nov. 11, 1966	James A. Lovell, Jr. Edwin E. Aldrin, Jr.	3 : 22 : 35	Longest extravehicular activity to date (Aldrin, 5 hrs 37 min).
Soyuz 1	Apr. 23, 1967	Vladimir M. Komarov	1 : 2 : 37	Cosmonaut killed in reentry accident.
Apollo 7	Oct. 11, 1968	Walter M. Schirra, Jr. Donn F. Eisele R. Walter Cunningham	10 : 20 : 9	First U.S. 3-man mission.
Soyuz 3	Oct. 26, 1968	Georgiy T. Beregovoy	3 : 22 : 51	Maneuvered near unmanned Soyuz 2.
Apollo 8	Dec. 21, 1968	Frank Borman James A. Lovell, Jr. William A. Anders	6 : 3 : 1	First manned orbit(s) of moon; first manned departure from Earth's sphere of influence; highest speed attained in manned flight to date.
Soyuz 4	Jan. 14, 1969	Vladimir A. Shatalov	2 : 23 : 23	Soyuz 4 and 5 docked and transferred 2 cosmonauts from Soyuz 5 to Soyuz 4.
Soyuz 5	Jan. 15, 1969	Boris V. Volynov Aleksey A. Yeliseyev Yevgeniy V. Khrunov	3 : 0 : 56	
Apollo 9	Mar. 3, 1969	James A. McDivitt David R. Scott Russell L. Schweickart	10 : 1 : 1	Successfully simulated in Earth orbit operation of lunar module to landing and takeoff from lunar surface and rejoining with command module.
Apollo 10	May 18, 1969	Thomas P. Stafford John W. Young Eugene A. Cernan	8 : 0 : 3	Successfully demonstrated complete system including lunar module descent to 14,300 m from the lunar surface.

APPENDIX C—*Continued*

U.S. and Soviet Manned Spaceflights, 1961–1990

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Apollo 11	July 16, 1969	Neil A. Armstrong Michael Collins Edwin E. Aldrin, Jr.	8 : 3 : 9	First manned landing on lunar surface and safe return to Earth. First return of rock and soil samples to Earth, and manned deployment of experiments on lunar surface.
Soyuz 6	Oct. 11, 1969	Georgiy Shonin Valeriy N. Kubasov	4 : 22 : 42	Soyuz 6, 7, and 8 operated as a group flight without actually docking. Each conducted certain experiments, including welding and Earth and celestial observation.
Soyuz 7	Oct. 12, 1969	Anatoliy V. Filipchenko Viktor N. Gorbatko Vladislav N. Volkov	4 : 22 : 41	
Soyuz 8	Oct. 13, 1969	Vladimir A. Shatalov Aleksey S. Yeliseyev	4 : 22 : 50	
Apollo 12	Nov. 14, 1969	Charles Conrad, Jr. Richard F. Gordon, Jr. Alan L. Bean	10 : 4 : 36	Second manned lunar landing. Explored surface of moon and retrieved parts of Surveyor 3 spacecraft, which landed in Ocean of Storms on Apr. 19, 1967.
Apollo 13	Apr. 11, 1970	James A. Lovell, Jr. Fred W. Haise, Jr. John L. Swigert, Jr.	5 : 22 : 55	Mission aborted; explosion in service module. Ship circled moon, with crew using LM as "lifeboat" until just before reentry.
Soyuz 9	June 1, 1970	Andriyan G. Nikolayev Vitaliy I. Sevastyanov	17 : 16 : 59	Longest manned spaceflight to date.
Apollo 14	Jan. 31, 1971	Alan B. Shepard, Jr. Stuart A. Roosa Edgar D. Mitchell	9 : 0 : 2	Third manned lunar landing. Mission demonstrated pinpoint landing capability and continued manned exploration.
Soyuz 10	Apr. 22, 1971	Vladimir A. Shatalov Aleksey S. Yeliseyev Nikolay N. Rukavishnikov	1 : 23 : 46	Docked with Salyut 1, but crew did not board space station launched 19 Apr. Crew recovered Apr. 24, 1971.
Soyuz 11	June 6, 1971	Georgiy T. Dobrovolskiy Vladislav N. Volkov Viktor I. Patsayev	23 : 18 : 22	Docked with Salyut 1 and Soyuz 11 crew occupied space station for 22 days. Crew perished during final phase of Soyuz 11 capsule recovery on June 30, 1971.
Apollo 15	July 26, 1971	David R. Scott Alfred M. Worden James B. Irwin	12 : 7 : 12	Fourth manned lunar landing and first Apollo "J" series mission, which carried Lunar Roving Vehicle. Worden's inflight EVA of 38 min 12 sec was performed during return trip.
Apollo 16	Apr. 16, 1972	John W. Young Charles M. Duke, Jr. Thomas K. Mattingly II	11 : 1 : 51	Fifth manned lunar landing, with Lunar Roving Vehicle.
Apollo 17	Dec. 7, 1972	Eugene A. Cernan Harrison H. Schmitt Ronald E. Evans	12 : 13 : 52	Sixth and final Apollo manned lunar landing, again with roving vehicle.
Skylab 2	May 25, 1973	Charles Conrad, Jr. Joseph P. Kerwin Paul J. Weitz	28 : 0 : 50	Docked with Skylab 1 (launched unmanned May 14) for 28 days. Repaired damaged station.
Skylab 3	July 28, 1973	Alan L. Bean Jack R. Lousma Owen K. Garriott	59 : 11 : 9	Docked with Skylab 1 for more than 59 days.
Soyuz 12	Sept. 27, 1973	Vasiliy G. Lazarev Oleg G. Makarov	1 : 23 : 16	Checkout of improved Soyuz.
Skylab 4	Nov. 16, 1973	Gerald P. Carr Edward G. Gibson William R. Pogue	84 : 1 : 16	Docked with Skylab 1 in long-duration mission; last of Skylab program.
Soyuz 13	Dec. 18, 1973	Petr I. Klimuk Valentin V. Lebedev	7 : 20 : 55	Astrophysical, biological, and earth resources experiments.
Soyuz 14	July 3, 1974	Pavel R. Popovich Yuriy P. Artyukhin	15 : 17 : 30	Docked with Salyut 3 and Soyuz 14 crew occupied space station.
Soyuz 15	Aug. 26, 1974	Gennadiy V. Sarafanov Lev. S. Demin	2 : 0 : 12	Rendezvoused but did not dock with Salyut 3.
Soyuz 16	Dec. 2, 1974	Anatoliy V. Filipchenko Nikolay N. Rukavishnikov	5 : 22 : 24	Test of ASTP configuration.

APPENDIX C—*Continued*

U.S. and Soviet Manned Spaceflights, 1961–1990

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz 17	Jan. 10, 1975	Aleksay A. Gubarev Georgiy M. Grechko	29 : 13 : 20	Docked with Salyut 4 and occupied station.
Anomaly	Apr. 5, 1975	Vasiliy G. Lazarev Oleg G. Makarov	0 : 0 : 20	Soyuz stages failed to separate; crew recovered after abort.
Soyuz 18	May 24, 1975	Petr I. Klimuk Vitaliy I. Sevastyanov	62 : 23 : 20	Docked with Salyut 4 and occupied station.
Soyuz 19	July 15, 1975	Aleksey A. Leonov Valeriy N. Kubasov	5 : 22 : 31	Target for Apollo in docking and joint experiments of ASTP mission.
Apollo (ASTP)	July 15, 1975	Thomas P. Stafford Donald K. Slayton Vance D. Brand	9 : 1 : 28	Docked with Soyuz 19 in joint experiments of ASTP mission.
Soyuz 21	July 6, 1976	Boris V. Volynov Vitaliy M. Zholobov	48 : 1 : 32	Docked with Salyut 5 and occupied station.
Soyuz 22	Sept. 15, 1976	Valeriy F. Bykovskiy Vladimir V. Aksenov	7 : 21 : 54	Earth resources study with multispectral camera system.
Soyuz 23	Oct. 14, 1976	Vyacheslav D. Zudov Valeriy I. Rozhdestvenskiy	2 : 0 : 6	Failed to dock with Salyut 5.
Soyuz 24	Feb. 7, 1977	Viktor V. Gorbatko Yuriy N. Glazkov	17 : 17 : 23	Docked with Salyut 5 and occupied station.
Soyuz 25	Oct. 9, 1977	Vladimir V. Kovalenok Valeriy V. Ryumin	2 : 0 : 46	Failed to achieve hard dock with Salyut 6 station.
Soyuz 26	Dec. 10, 1977	Yuriy V. Romanenko Georgiy M. Grechko	37 : 10 : 6	Docked with Salyut 6. Crew returned in Soyuz 27; crew duration 96 days 10 hrs.
Soyuz 27	Jan. 10, 1978	Vladimir A. Dzhanibekov Oleg G. Makarov	64 : 22 : 53	Docked with Salyut 6. Crew returned in Soyuz 26; crew duration 5 days 22 hrs 59 min.
Soyuz 28	Mar. 2, 1978	Aleksey A. Gubarev Vladimir Remek	7 : 22 : 17	Docked with Salyut 6. Remek was first Czech cosmonaut to orbit.
Soyuz 29	June 15, 1978	Vladimir V. Kovalenok Aleksandr S. Ivanchenkov	79 : 15 : 23	Docked with Salyut 6. Crew returned in Soyuz 31; crew duration 139 days 14 hrs 48 min.
Soyuz 30	June 27, 1978	Petr I. Klimuk Miroslaw Hermaszewski	7 : 22 : 4	Docked with Salyut 6. Hermaszewski was first Polish cosmonaut to orbit.
Soyuz 31	Aug. 26, 1978	Valeriy F. Bykovskiy Sigmund Jaehn	67 : 20 : 14	Docked with Salyut 6. Crew returned in Soyuz 29; crew duration 7 days 20 hrs 49 min. Jaehn was first German Democratic Republic cosmonaut to orbit.
Soyuz 32	Feb. 25, 1979	Vladimir A. Lyakhov Valeriy V. Ryumin Nikolay N. Rukavishnikov	108 : 4 : 24	Docked with Salyut 6. Crew returned in Soyuz 34; crew duration 175 days 36 min.
Soyuz 33	Apr. 10, 1979	Georgi I. Ivanov	1 : 23 : 1	Failed to achieve docking with Salyut 6 station. Ivanov was first Bulgarian cosmonaut to orbit.
Soyuz 34	June 6, 1979	(unmanned at launch)	73 : 18 : 17	Docked with Salyut 6, later served as ferry for Soyuz 32 crew while Soyuz 32 returned unmanned.
Soyuz 35	Apr. 9, 1980	Leonid I. Popov Valeriy V. Ryumin	55 : 1 : 29	Docked with Salyut 6. Crew returned in Soyuz 37. Crew duration 184 days 20 hrs 12 min.
Soyuz 36	May 26, 1980	Valeriy N. Kubasov Bertalan Farkas	65 : 20 : 54	Docked with Salyut 6. Crew returned in Soyuz 35. Crew duration 7 days 20 hrs 46 min. Farkas was first Hungarian to orbit.
Soyuz T-2	June 5, 1980	Yuriy V. Malyshev Vladimir V. Aksenov	3 : 22 : 21	Docked with Salyut 6. First manned flight of new-generation ferry.
Soyuz 37	July 23, 1980	Viktor V. Gorbatko Pham Tuan	79 : 15 : 17	Docked with Salyut 6. Crew returned in Soyuz 36. Crew duration 7 days 20 hrs 42 min. Pham was first Vietnamese to orbit.
Soyuz 38	Sept. 18, 1980	Yuriy V. Romanenko Arnaldo Tamayo Mendez	7 : 20 : 43	Docked with Salyut 6. Tamayo was first Cuban to orbit.
Soyuz T-3	Nov. 27, 1980	Leonid D. Kizim Oleg G. Makarov Gennadiy M. Strekalov	12 : 19 : 8	Docked wtih Salyut 6. First 3-man flight in Soviet program since 1971.

U.S. and Soviet Manned Spaceflights, 1961–1990

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz T-4	Mar. 12, 1981	Vladimir V. Kovalenok Viktor P. Savinykh	74 : 18 : 38	Docked with Salyut 6.
Soyuz 39	Mar. 22, 1981	Vladimir A. Dzhanibekov Jugderdemidiyn Gurragcha	7 : 20 : 43	Docked with Salyut 6. Gurragcha first Mongolian cosmonaut to orbit.
Space Shuttle Columbia (STS 1)	Apr. 12, 1981	John W. Young Robert L. Crippen	2 : 6 : 21	First flight of Space Shuttle, tested spacecraft in orbit. First landing of airplanelike craft from orbit for reuse.
Soyuz 40	May 14, 1981	Leonid I. Popov Dumitru Prunariu	7 : 20 : 41	Docked with Salyut 6. Prunariu first Romanian cosmonaut to orbit.
Space Shuttle Columbia (STS 2)	Nov. 12, 1981	Joe H. Engle Richard H. Truly	2 : 6 : 13	Second flight of Space Shuttle, first scientific payload (OSTA 1). Tested remote manipulator arm. Returned for reuse.
Space Shuttle Columbia (STS 3)	Mar. 22, 1982	Jack R. Lousma C. Gordon Fullerton	8 : 4 : 49	Third flight of Space Shuttle, second scientific payload (OSS 1). Second test of remote manipulator arm. Flight extended 1 day because of flooding at primary landing site; alternate landing site used. Returned for reuse.
Soyuz T-5	May 13, 1982	Anatoliy Berezovoy Valentin Lebedev	211: 9 : 5	Docked with Salyut 7. Crew duration of 211 days. Crew returned in Soyuz T-7.
Soyuz T-6	June 24, 1982	Vladimir Dzhanibekov Aleksandr Ivanchenkov Jean-Loup Chretien	7 : 21 : 51	Docked with Salyut 7. Chretien first French cosmonaut to orbit.
Space Shuttle Columbia (STS 4)	June 27, 1982	Thomas K. Mattingly II Henry W. Hartsfield, Jr.	7 : 1 : 9	Fourth flight of Space Shuttle, first DoD payload, additional scientific payloads. Returned July 4. Completed orbital flight testing program. Returned for reuse.
Soyuz T-7	Aug. 19, 1982	Leonid Popov Aleksandr Serebrov Svetlana Savitskaya	7 : 21 : 52	Docked with Salyut 7. Savitskaya second Soviet woman to orbit. Crew returned in Soyuz T-5.
Space Shuttle Columbia (STS 5)	Nov. 11, 1982	Vance D. Brand Robert F. Overmyer Joseph P. Allen William B. Lenoir	5 : 2 : 14	Fifth flight of Space Shuttle, first operational flight; launched 2 commercial satellites (SBS 3 and Anik C-3); first flight with 4 crew members. EVA test cancelled when spacesuits malfunctioned.
Space Shuttle Challenger (STS 6)	Apr. 4, 1983	Paul J. Weitz Karol J. Bobko Donald H. Peterson Story Musgrave	5 : 0 : 24	Sixth flight of Space Shuttle, launched TDRS 1.
Soyuz T-8	Apr. 20, 1983	Vladimir Titov Gennady Strekalov Aleksandr Serebrov	2 : 0 : 18	Failed to achieve docking with Salyut 7 station.
Space Shuttle Challenger (STS 7)	June 18, 1983	Robert L. Crippen Frederick H. Hauck John M. Fabian Sally K. Ride Norman T. Thagard	6 : 2 : 24	Seventh flight of Space Shuttle, launched 2 commercial satellites (Anik C-2 and Palapa B-1), also launched and retrieved SPAS 01; first flight with 5 crew members, including first woman U.S. astronaut.
Soyuz T-9	June 28, 1983	Vladimir Lyakhov Aleksandr Aleksandrov	149: 9 : 46	Docked with Salyut 7 station.
Space Shuttle Challenger (STS 8)	Aug. 30, 1983	Richard H. Truly Daniel C. Brandenstein Dale A. Gardner Guion S. Bluford, Jr. William E. Thornton	6 : 1 : 9	Eighth flight of Space Shuttle, launched one commercial satellite (Insat 1-B), first flight of U.S. black astronaut.
Space Shuttle Columbia (STS 9)	Nov. 28, 1983	John W. Young Brewster W. Shaw Owen K. Garriott Robert A. R. Parker Byron K. Lichtenberg Ulf Merbold	10 : 7 : 47	Ninth flight of Space Shuttle, first flight of Spacelab 1, first flight of 6 crew members, one of whom was West German, first non-U.S. astronaut to fly in U.S. space program.

APPENDIX C—*Continued*

U.S. and Soviet Manned Spaceflights, 1961–1990

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle Challenger (STS-41B)	Feb. 3, 1984	Vance D. Brand Robert L. Gibson Bruce McCandless Ronald E. McNair Robert L. Stewart	7 : 23 : 16	Tenth flight of Space Shuttle, two communication satellites failed to achieve orbit. First use of Manned Maneuvering Unit (MMU) in space.
Soyuz T-10	Feb. 8, 1984	Leonid Kizim Vladimir Solovev Oleg Atkov	62 : 22 : 43	Docked with Salyut 7 station. Crew set space duration record of 237 days. Crew returned in Soyuz T-11.
Soyuz T-11	Apr. 3, 1984	Yuriy Malyshev Gennadiy Strekalov Rakesh Sharma	181 : 21 : 48	Docked with Salyut 7 station. Sharma first Indian in space. Crew returned in Soyuz T-10.
Space Shuttle Challenger (STS-41C)	Apr. 6, 1984	Robert L. Crippen Frances R. Scobee Terry J. Hart George D. Nelson James D. van Hoften	6 : 23 : 41	Eleventh flight of Space Shuttle, deployment of LDEF-1, for later retrieval, Solar Maximum Satellite retrieved, repaired, and redeployed.
Soyuz T-12	July 17, 1984	Vladimir Dzhanibekov Svetlana Savistskaya Igor Volk	11 : 19 : 14	Docked with Salyut 7 station. First woman extravehicular activity.
Space Shuttle Discovery (STS-41D)	Aug. 30, 1984	Henry W. Hartsfield Michael L. Coats Richard M. Mullane Steven A. Hawley Judith A. Resnick Charles D. Walker	6 : 0 : 56	Twelfth flight of Space Shuttle. First flight of U.S. non-astronaut.
Space Shuttle Challenger (STS-41G)	Sept. 5, 1984	Robert L. Crippen Jon A. McBride Kathryn D. Sullivan Sally K. Ride David Leestma Paul D. Scully-Power Marc Garneau	8 : 5 : 24	Thirteenth flight of Space Shuttle, first flight of 7 crewmembers, including first flight of two U.S. women and one Canadian.
Space Shuttle Discovery (STS-51A)	Nov. 8, 1984	Frederick H. Hauck David M. Walker Joseph P. Allen Anna L. Fisher Dale A. Gardner	7 : 23 : 45	Fourteenth flight of Space Shuttle, first retrieval and return of two disabled communications satellites (Westar 6, Palapa B2) to Earth.
Space Shuttle Discovery (STS-51C)	Jan. 24, 1985	Thomas K. Mattingly Loren J. Shriver Ellison S. Onizuka James F. Buchli Gary E. Payton	3 : 1 : 33	Fifteenth STS flight. Dedicated DoD mission.
Space Shuttle Discovery (STS-51D)	Apr. 12, 1985	Karol J. Bobko Donald E. Williams M. Rhea Seddon S. David Griggs Jeffrey A. Hoffman Charles D. Walker E. J. Garn	6 : 23 : 55	Sixteenth STS flight. Two communications satellites. First U.S. Senator in space.
Space Shuttle Challenger (STS-51B)	Apr. 29, 1985	Robert F. Overmyer Frederick D. Gregory Don L. Lind Norman E. Thagard William E. Thornton Lodewijk Vandenberg Taylor Wang	7 : 0 : 9	Seventeenth STS flight. Spacelab-3 in cargo bay of shuttle.
Soyuz T-13	June 5, 1985	Vladimir Dzhanibekov Viktor Savinykh	112: 3 : 12	Repair of Salyut-7. Dzhanibekov returned to Earth with Grechko on Soyuz T-13 spacecraft, Sept. 26, 1985.

U.S. and Soviet Manned Spaceflights, 1961–1990

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle Discovery (STS-51G)	June 17, 1985	Daniel C. Brandenstein John O. Creighton Shannon W. Lucid John M. Fabian Steven R. Nagel Patrick Baudry Sultan bin Salman bin Abdul-Aziz Al-Saud	7: 1 : 39	Eighteenth STS flight. Three communications satellites. One reusable payload, Spartan-1. First U.S. flight with French and Saudi Arabian crewmen.
Space Shuttle Challenger (STS-51F)	July 29, 1985	Charles G. Fullerton Roy D. Bridges Karl C. Henize Anthony W. England F. Story Musgrave Loren W. Acton John-David F. Bartoe	7 : 22 : 45	Nineteenth STS flight. Spacelab-2 in cargo bay.
Space Shuttle Discovery (STS-51I)	Aug. 27, 1985	Joe H. Engle Richard O. Covey James D. van Hoften William F. Fisher John M. Lounge	7 : 2 : 18	Twentieth STS flight. Launched three communications satellites. Repaired Syncom IV-3.
Soyuz T-14	Sept. 17, 1985	Vladimir Vasyutin Georgiy Grechko Aleksandr Volkov	64 : 21 : 52	Docked with Salyut-7 station. Viktor Savinykh, Aleksandr Volkov and Vladimir Vasyutin returned to Earth Nov. 21, 1985, when Vasyutin became ill.
Space Shuttle Atlantis (STS-51J)	Oct. 3, 1985	Karol J. Bobko Ronald J. Grabe Robert A. Stewart David C. Hilmers William A. Pailes	4 : 1 : 45	Twenty-first STS flight. Dedicted DoD mission.
Space Shuttle Challenger (STS-61A)	Oct. 30, 1985	Henry W. Hartsfield Steven R. Nagel Bonnie J. Dunbar James F. Buchli Guion S. Bluford Ernst Messerschmid Reinhard Furrer Wubbo J. Ockels	7 : 0 : 45	Twenty-second STS flight. Dedicated German Spacelab D-1 in shuttle cargo bay.
Space Shuttle Atlantis (STS-61B)	Nov. 27, 1985	Brewster H. Shaw Bryan D. O'Connor Mary L. Cleve Sherwood C. Spring Jerry L. Ross Rudolfo Neri Vela Charles D. Walker	6 : 22 : 54	Twenty-third STS flight. Launched three communications satellites. First flight of Mexican astronaut.
Space Shuttle Columbia (STS-61C)	Jan. 12, 1986	Robert L. Gibson Charles F. Bolden, Jr. Franklin Chang-Diaz Steven A. Hawley George D. Nelson Roger Cenker Bill Nelson	6 : 2 : 4	Twenty-fourth STS flight. Launched one communications satellite. First member of U.S. House of Representatives in space.
Soyuz T-15	Mar. 13, 1986	Leonid Kizim Vladimir Solovyov	125: 1 : 1	Docked with MIR space station on May 5/6 transferred to Salyut 7 complex. On June 25/26 transferred from Salyut 7 back to MIR.
Soyuz TM-2	Feb. 5, 1987	Yuriy Romanenko Aleksandr Laveykin	174: 3 : 26	Docked with MIR space station. Romanenko established long distance stay in space record of 326 days.

U.S. and Soviet Manned Spaceflights, 1961–1990

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz TM-3	July 22, 1987	Aleksandr Viktorenko Aleksandr Aleksandrov Mohammed Faris	160 : 7 : 16	Docked with MIR space station. Aleksandr Aleksandrov remained in MIR 160 days, returned with Yuriy Romanenko. Viktorenko and Faris returned in Soyuz TM-2, July 30 with Aleksandr Laveykin who experienced medical problems. Mohammed Faris first Syrian in space.
Soyuz TM-4	Dec. 21, 1987	Vladimir Titov Musa Manarov Anatoliy Levchenko	180 : 5	Docked with MIR space station. Crew of Yuriy Romanenko, Aleksandr Aleksandrov, and Anatoliy Levchenko returned Dec. 29 in Soyuz TM-3.
Soyuz TM-5	Jun. 7, 1988	Viktor Savinykh Anatoly Solovyev Aleksandr Aleksandrov	9 : 20 : 13	Docked with MIR space station, Aleksandrov first Bulgarian in space. Crew returned Jun. 17 in Soyuz TM-4.
Soyuz TM-6	Aug. 29, 1988	Vladimir Lyakhov Valeriy Polyakov Abdul Mohmand	8 : 19 : 27	Docked with MIR space station, Mohmand first Afghanistan in space. Crew returned Sep. 7 in Soyuz TM-5
STS-26	Sep. 29, 1988	Frederick H. Hauck Richard O. Covey John M. Lounge David C. Hilmers George D. Nelson	4 : 1	Twenty-sixth STS flight. Launched TDRS 3.
Soyuz TM-7	Nov. 26, 1988	Aleksandr Volkov Sergey Krikalev Jean-Loup Chretien	151 : 11	Docked with MIR space station. Soyuz TM-6 returned with Chretien, Vladimir Titov, and Musa Manarov. Titov and Manarov completed 366-day mission Dec. 21. Crew of Krikalev, Volkov, and Valeriy Polyakov returned Apr. 27, 1989 in Soyuz TM-7.
STS-27	Dec. 2, 1988	Robert "Hoot" Gibson Guy S. Gardner Richard M. Mullane Jerry L. Ross William M. Shepherd	4 : 9 : 6	Twenty-seventh STS flight. Dedicated DoD mission.
STS-29	Mar. 13, 1989	Michael L. Coats John E. Blaha James P. Bagian James F. Buchli Robert C. Springer	4 : 23 : 39	Twenty-eighth STS flight. Launched TDRS-4.
STS-30	May 4, 1989	David M. Walker Ronald J. Grabe Norman E. Thagard Mary L. Cleave Mark C. Lee	4 : 0 : 57	Twenty-ninth STS flight. Venus orbiter Magellan launched.
STS-28	Aug. 8, 1989	Brewster H. Shaw Richard N. Richards James C. Adamson David C. Leestma Mark N. Brown	5 : 1	Thirtieth STS flight. Dedicated DOD mission.
Soyuz TM-8	Sep. 5, 1989	Aleksandr Viktorenko Aleksandr Serebrov	166 : 6	Docked with MIR space station. Crew of Viktorenko and Serebrov returned in Soyuz TM-8, Feb. 9, 1990.

U.S. and Soviet Manned Spaceflights, 1961–1990

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
STS-34	Oct. 18, 1989	Donald E. Williams Michael J. McCulley Shannon W. Lucid Franklin R. Chang-Diaz Ellen S. Baker	4 : 23 : 39	Thirty-first STS flight. Launched Jupiter probe and orbiter Galileo.
STS-33	Nov. 23, 1989	Frederick D. Gregory John E. Blaha Kathryn C. Thornton F. Story Musgrave Manley L. "Sonny" Carter	5 : 0 : 7	Thirty-second STS flight. Dedicated DOD mission.
STS-32	Jan. 9, 1990	Daniel C. Brandenstein James D. Wetherbee Bonnie J. Dunbar Marsha S. Ivins G. David Low	10 : 21	Thirty-third STS flight. Launched Syncom IV-5 and retrieved Long Duration Exposure Facility (LDEF).
Soyuz TM-9	Feb. 11, 1990	Anatoliy Solovyov Aleksandr Balandin	178 : 22 : 19	Docked with MIR space station. Crew returned Aug. 9, 1990, in Soyuz TM-9.
STS-36	Feb. 28, 1990	John O. Creighton John H. Casper David C. Hilmers Richard H. Mullane Pierre J. Thout	4 : 10 : 19	Thirty-fourth STS flight. Dedicated DOD mission.
STS-31	Apr. 24, 1990	Loren J. Shriver Charles F. Bolden, Jr. Steven A. Hawley Bruce McCandless II Kathryn D. Sullivan	5 : 1 : 16	Thirty-fifth STS flight. Launched Hubble Space Telescope (HST).
Soyuz TM-10	Aug. 1, 1990	Gennadiy Manakov Gennadiy Strekalov	mission in progress	Docked with MIR space station.

APPENDIX D

U.S. Space Launch Vehicles

Vehicle	Stages/(engines)	Propellant[a]	Thrust (kilonewtons)	Max. Dia. x Height (m)	Max. Payload (kg)[b] 185-Km Orbit	Max. Payload (kg)[b] Geosynch.- Transfer Orbit	Max. Payload (kg)[b] Circular Sun-Synch. Orbit	First Launch[c]
Scout	1. Algol IIIA	Solid	431.1	1.14x22.9	255 205[d]	–	155[d]	1979(60)
	2. Castor IIA	Solid	285.2					
	3. Antares IIIA	Solid	83.1					
	4. Altair IIIA	Solid	25.6					
Delta 3900 Series (Thor-Delta)[e]	1. Thor plus	LOX/RP-1	912.0	2.44x35.4	3,045 2,180[d]	1,275	2,135[d]	1982(60)
	9 TX 526-2	Solid	375 each					
	2. Delta	N_20_4/Aerozine-50	44.2					
Delta II	1. Thor plus	LOX/RP-1	920.8	2.90x39.62	–	1,819	–	1989
	9 TX 526-2	Solid	432 each					
	2. Delta	N_20_4/Aerozine-50	43.0					
Atlas E	Atlas booster (MA-3) & sustainer	LOX/RP-1	1,722.0	3.05x28.1	2,090[d,f]	–	1,500[d]	1972(59)
Atlas-Centaur	1. Atlas booster (MA-5) & sustainer	LOX/RP-1	1,913.0	3.05x45.0	6,100	2,360	–	1984(72)
	2. Centaur	LOX/LH_2	146.0					
Titan IV	1. Two 7-segment, 3.05 m dia	Solid	12,402.0	5.08x62.2	17,690	2,404		1989
	2. (LR-87)	N_20_4/Aerozine	2,452.0					
	3. (LR-91)	N_20_4/Aerozine	472.0					
	4. IUS 1st stage	Solid	185.0					
	5. IUS 2nd stage	Solid	76.0					
					185-Km Orbit	24-Hour Polar Orbit	Sun-synch. Transfer Orbit	
Titan II	1. (LR-87[2])	N_20_4/Aerozine-50	2,108.4	3.05x28.5	2,200 1,905[d]	–	–	1988 (62)
	2. (LR-91)	N_20_4/Aerozine-50	444.8					
Titan IIIB-Agena	1. (LR-87)	N_20_4/Aerozine	2,341.0	3.05x48.4	3,600[d]		3,060[d]	1966
	2. (LR-91)	N_20_4/Aerozine	455.1					
	3. Agena	IRFNA/UDMH	71.2					
Titan III(34)D/IUS	1. Two 5½-segment, 3.05 m dia	Solid	11,564.8	3.05x48.0	14,920	1,850[d]	–	1982
	2. LR-87	N_20_4/Aerozine	2,366.3					
	3. LR-91	N_20_4/Aerozine	449.3					
	4. IUS 1st stage	Solid	275.8					
	5. IUS 2nd stage	Solid	115.7					
Titan III(34)D/ Transtage	Same as Titan III(34)D plus:			3.05x46.9	14,920	1,855[d]	–	1984[h]
	4. Transtage	N_20_4/Aerozine	69.8					
					280- to 420-Km Orbit			
Space Shuttle (reusable)	1. Orbiter; 3 main engines (SSMEs) fire in parallel with SRBs	LOX/LH_2	1,670 each	23.79x37.24 wing long span	24,900 in full performance configuration			1981
	2. Two solid-fueled rocket boosters (SRBs) fire in parallel with SSMEs	AL/NH_4CLO_4/ PBAN	11,790 each	3.71x45.45				
	Mounted on external tank (ET)			8.40x46.88				

[a] Propellant abbreviations used are as follows: liquid oxygen and a modified kerosene = LOX/RP,RJ; solid propellant combining in a single mixture both fuel and oxidizer = Solid; inhibited red-fuming nitric acid and unsymmetrical dimethylhydrazine = IRFNA/UDMH; nitrogen tetroxide and UDMH/N_2H_4 = N_2O_4/aerozine; liquid oxygen and liquid hydrogen = LOX/LH_2; aluminum, ammonium perchlorate, and polybutadiene acrolonitrile terpolymer = AL/NH_4CLO_4/PBAN.

[b] Due east launch except as indicated.

[c] The date of first launch applies to this latest modification with a date in parentheses for the initial version.

[d] Polar launch.

[e] Maximum performance based on 3920, 3920/PAM configurations. PAM = payload assist module.

[f] With dual TE 364-4.

[g] With 96° flight azimuth.

[h] Initial operational capability in December 1982; launch to be scheduled as needed.

NOTE: Data should not be used for detailed NASA mission planning without concurrence of the director of Space Transportation System Support Programs.

Appendix E-1

Space Activities of the U.S. Government

HISTORICAL BUDGET SUMMARY—BUDGET AUTHORITY

(in millions of dollars)

Fiscal Year	NASA		Defense	Other	Energy	Commerce	Interior	Agriculture	NSF	DOT	EPA	Total Space
	Total	Space[a]										
1959	330.9	260.9	489.5	0.0	34.3	...	...	...	...	...	...	784.7
1960	523.6	461.5	560.9	0.0	43.3	...	...	...	0.1	...	...	1,065.8
1961	964.0	926.0	813.9	0.0	67.7	...	...	...	0.6	...	...	1,808.2
1962	1,824.9	1,796.8	1,298.2	0.0	147.8	50.7	...	...	1.3	...	...	3,294.8
1963	3,673.0	3,626.0	1,549.9	0.0	213.9	43.2	...	...	1.5	...	...	5,434.5
1964	5,099.7	5,016.3	1,599.3	0.0	210.0	2.8	...	...	3.0	...	...	6,831.4
1965	5,249.7	5,137.6	1,573.9	0.0	228.6	12.2	...	...	3.2	...	...	6,955.5
1966	5,174.9	5,064.5	1,688.8	0.0	186.8	26.5	...	...	3.2	...	...	6,969.8
1967	4,965.6	4,830.2	1,663.6	0.0	183.6	29.3	...	...	2.8	...	...	6,709.5
1968	4,587.3	4,430.0	1,921.8	0.0	145.1	28.1	0.2	0.5	3.2	...	...	6,528.9
1969	3,990.9	3,822.0	2,013.0	0.0	118.0	20.0	0.2	0.7	1.9	...	...	5,975.8
1970	3,745.8	3,547.0	1,678.4	0.0	102.8	8.0	1.1	0.8	2.4	...	...	5,340.5
1971	3,311.2	3,101.3	1,512.3	127.3	94.8	27.4	1.9	0.8	2.4	...	...	4,740.9
1972	3,306.6	3,071.0	1,407.0	96.7	55.2	31.3	5.8	1.6	2.8	...	...	4,574.7
1973	3,406.2	3,093.2	1,623.0	108.7	54.2	39.7	10.3	1.9	2.6	...	...	4,824.9
1974	3,036.9	2,758.5	1,766.0	115.8	41.7	60.2	9.0	3.1	1.8	...	...	4,640.3
1975	3,229.1	2,915.3	1,892.4	106.6	29.6	64.4	8.3	2.3	2.0	...	...	4,914.3
1976	3,550.3	3,225.4	1,983.3	111.2	23.3	71.5	10.4	3.6	2.4	...	...	5,319.9
Transitional Quarter	931.8	849.2	460.4	30.9	4.6	22.2	2.6	0.9	0.6	...	...	1,340.5
1977	3,817.8	3,440.2	2,411.9	130.7	21.7	90.8	9.5	6.3	2.4	...	...	5,982.8
1978	4,060.1	3,622.9	2,738.3	157.0	34.4	102.8	9.7	7.7	2.4	...	...	6,518.2
1979	4,595.5	4,030.4	3,035.6	177.5	58.6	98.4	9.9	8.2	2.4	...	...	7,243.5
1980	5,240.2	4,680.4	3,848.4	160.0	39.6	92.6	11.7	13.7	2.4	...	...	8,688.8
1981	5,518.4	4,992.4	4,827.7	157.7	40.5	87.0	12.3	15.5	2.4	...	...	9,977.8
1982	6,043.9[b]	5,527.6	6,678.7	234.4	60.6	144.5	12.1	15.2	2.0	...	...	12,440.7
1983	6,875.3[c]	6,327.9	9,018.9	241.7	38.9	177.8	4.6	20.4	...[d]	...	...	15,588.5
1984	7,248.0	6,648.3	10,194.9	292.5	34.1	236.0	3.0	19.4	...	...	...	17,135.7
1985	7,572.6	6,924.9	12,767.9	473.7	34.0	422.9	2.0	14.8	...	...	...	20,166.5
1986	7,766.0	7,165.0	14,126.0	368.4	34.6	308.9	2.0	22.9	...	...	...	21,659.4
1987	10,507.0	9,809.0[e]	16,286.8	352.1	47.6	277.9	7.6	18.5	...	0.5	...	26,447.9
1988	9,025.8	8,302.4	17,678.7	625.6	240.8	351.5	13.6	18.3	...	1.4	...	26,606.7
1989	10,969.0	10,097.5	17,906.1	439.7	97.2	301.3	17.0	20.5	...	2.7	1.0	28,443.3
1990	13,073.4	12,141.6	19,382.4	330.2	78.6	201.7	19.0	26.4	...	3.5	1.0	31,854.2
1991 [est.]	14,647.0	13,602.8	20,443.0	372.7	106.2	210.5	24.0	27.4	...	3.6	1.0	34,418.5

SOURCE: Office of Management and Budget.

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[a] Excludes amounts for air transportation (subfunction 402).

[b] Includes $33.5 million unobligated funds that lapsed.

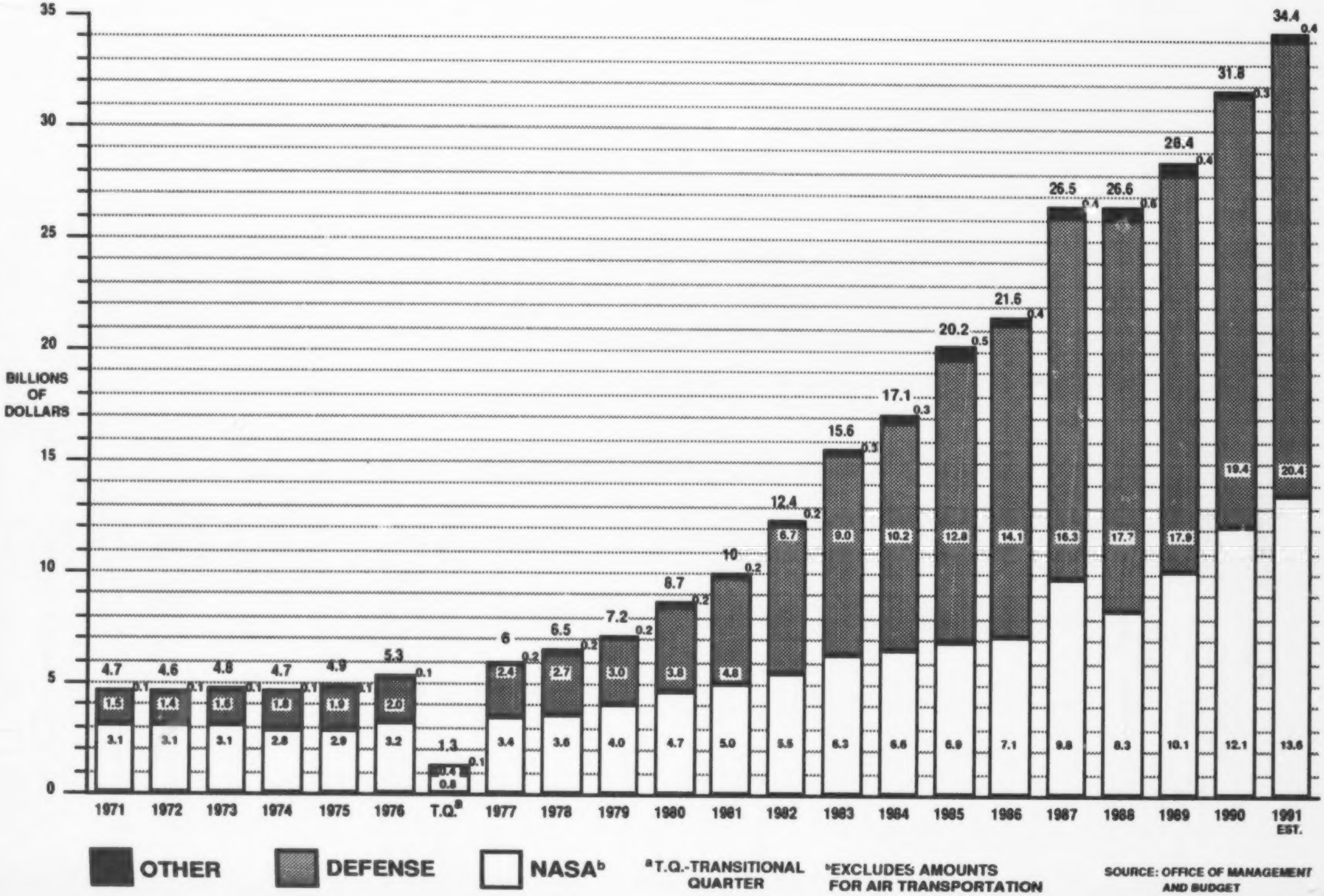
[c] Includes $37.6 million for reappropriation of prior year funds.

[d] NSF funding of balloon research transferred to NASA.

[e] Includes $2.1 billion for replacement of shuttle orbiter Challenger.

U.S. Space Budget—Budget Authority FY 1971-1990

(may not add because of rounding)



ªT.Q.-TRANSITIONAL QUARTER

ᵇEXCLUDES AMOUNTS FOR AIR TRANSPORTATION

SOURCE: OFFICE OF MANAGEMENT AND BUDGET

APPENDIX E-2

Space Activities Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority			Budget Outlays		
	1989 Actual	1990 Actual	1991 Estimate	1989 Actual	1990 Actual	1991 Estimate
NASA[a]	10,098	12,142	13,603	10,195	12,292	13,129
Defense	17,906	19,382	20,443	14,504	15,448	16,314
Energy	97	79	106	97	79	106
Commerce	301	202	211	306	232	223
Interior	17	19	24	17	19	24
NSF[b]	0	0	0	0	0	0
Agriculture	21	26	27	21	26	27
Transportation	3	4	4	2	3	4
EPA	1	1	1	1	1	1
TOTAL	28,443	31,854	34,419	25,143	28,100	29,828

[a] Excludes amounts for air transportation.

[b] NSF funding for balloon research transferred to NASA.

SOURCE: Office of Management and Budget.

APPENDIX E-3

Aeronautics Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority			Budget Outlays		
	1989 Actual	1990 Actual	1991 Estimate	1989 Actual	1990 Actual	1991 Estimate
NASA[a]	872	932	1,044	855	889	1,040
Department of Defense[b]	8,240	8,552	8,979	6,420	7,711	8,317
Department of Transportation[c]	1,544	1,891	2,300	1,216	1,471	1,870
TOTAL	10,656	11,375	12,324	8,491	10,071	11,227

[a] Research and Development, Construction of Facilities, Research and Program Management.

[b] Research, Development, Testing, and Evaluation of aircraft and related equipment.

[c] Federal Aviation Administration: Research, Engineering, and Development; Facilities, Engineering, and Development.

SOURCE: Office of Management and Budget.

APPENDIX F-1

EXECUTIVE ORDER 12675

ESTABLISHING THE NATIONAL SPACE COUNCIL

By the authority vested in me as President by the Constitution and laws of the United States of America, and in order to provide a coordinated process for developing a national space policy and strategy and for monitoring its implementation, it is hereby ordered as follows:

Section. 1. Establishment and Composition of the National Space Council.
(a) There is established the National Space Council ("the Council").
(b) The Council shall be composed of the following members:
  (1) The Vice President, who shall be Chairman of the Council;
  (2) The Secretary of State;
  (3) The Secretary of the Treasury;
  (4) The Secretary of Defense;
  (5) The Secretary of Commerce;
  (6) The Secretary of Transportation;
  (7) The Director of the Office of Management and Budget;
  (8) The Chief of Staff to the President;
  (9) The Assistant to the President for National Security Affairs;
  (10) The Assistant to the President for Science and Technology;
  (11) The Director of Central Intelligence; and
  (12) The Administrator of the National Aeronautics and Space Administration.
(c) The Chairman shall, from time to time, invite the following to participate in meetings of the Council:
  (1) The Chairman of the Joint Chiefs of Staff; and
  (2) The heads of other executive departments and agencies and other senior officials in the Executive Office of the President.

Section 2. Functions of the Council.
(a) The Council shall advise and assist the President on national space policy and strategy, and perform such other duties as the President may from time to time prescribe.
(b) In addition, the Council is directed to:
  (1) review United States Government space policy, including long-range goals, and develop a strategy for national space activities;
  (2) develop recommendations for the President on space policy and space-related issues;
  (3) monitor and coordinate implementation of the objectives of the President's national space policy by executive departments and agencies; and
  (4) foster close coordination, cooperation, and technology and information exchange among the civil, national security, and commercial space sectors, and facilitate resolution of differences concerning major space and space-related policy issues.
(c) The creation and operation of the Council shall not interfere with existing lines of authority and responsibilities in the departments and agencies.

Section 3. Responsibilities of the Chairman.
(a) The Chairman shall serve as the President's principal advisor on national space policy and strategy.
(b) The Chairman shall, in consultation with the members of the Council, establish procedures for the Council and establish the agenda for Council activities.
(c) The Chairman shall report to the President on the activities and recommendations of the Council. The Chairman shall advise the Council as appropriate regarding the President's directions with respect to the Council's activities and national space policy generally.
(d) The Chairman shall authorize the establishment of such committees of the Council, including an executive committee, and of such working groups, composed of senior designees of the Council members and of other officials invited to participate in Council meetings, as he deems necessary or appropriate for the efficient conduct of Council functions.

Section 4. National Space Policy Planning Process.
(a) The Council will establish a process for developing and monitoring the implementation of national space policy and strategy.
(b) To implement this process, each agency represented on the Council shall provide such information regarding its current and planned space activities as the Chairman shall request.
(c) The head of each executive department and agency shall ensure that its space-related activities conform to national space policy and strategy.

Section 5. Establishment of Vice President's Space Policy Advisory Board.
(a) The Vice President shall establish; in accordance with the provisions of the Federal Advisory Committee Act, as amended (5 U.S.C. App. 2), governing Presidential advisory committees, an advisory committee of private citizens to advise the Vice President on the space policy of the United States ("the Board").
(b) The Board shall be composed and function as follows:
  (1) The Board shall be composed of members appointed by the Vice President.
  (2) The Vice President shall designate a Chairman from among the members of the Board. The Executive Secretary of the National Space Council shall serve as the Secretary to the Board.

(3) Members of the board shall serve without any compensation for their work on the Board. However, they shall be entitled to travel expenses, including per diem in lieu of subsistence, as authorized by law, for persons serving intermittently in the Government service (5 U.S.C. 5701-5707), to the extent funds are available for that purpose.

(4) Necessary expenses of the Board shall be paid from funds available for the expenses of the National Space Council.

(5) Notwithstanding the provisions of any other Executive order, the responsibilities of the President under the Federal Advisory Committee Act, as amended, except that of reporting annually to the Congress, which are applicable to the Board established by this order, shall be performed on a reimbursable basis by the Director of the Office of Administration in the Executive Office of the President, in accordance with the guidelines and procedures established by the Administrator of General Services.

Section 6. Microgravity Research Board.

Section 1(c) of Executive Order No. 12660 is amended by deleting "Economic Policy Council" and inserting in lieu thereof "National Space Council."

Section 7. Administrative Provisions.

(a) The Office of Administration in the Executive Office of the President shall provide the Council with such administrative support on a reimbursable basis as may be necessary for the performance of the functions of the Council.

(b) The President shall appoint an Executive Secretary who shall appoint such staff as may be necessary to assist in the performance of the Council's functions.

(c) All Federal departments, agencies, and interagency councils and committees having an impact on space policy shall extend, as appropriate, such cooperation and assistance to the Council as is necessary to carry out its responsibilities under this order.

(d) The head of each agency serving on the Council or represented on any working group or committee of the Council shall provide such administrative support as may be necessary, in accordance with law and subject to the availability of appropriations, to enable the agency head or its representative to carry out his responsibilities.

Section 8. Report.

The Council shall submit an annual report setting forth its assessment of and recommendations for the space policy and strategy of the United States Government.

George Bush

The White House,
April 20, 1989.

APPENDIX F-2

THE WHITE HOUSE

Office of the Press Secretary

For Immediate Release November 16, 1989

FACT SHEET
U.S. National Space Policy

On November 2, 1989, the President approved a national space policy that updates and reaffirms U.S. goals and activities in space. The updated policy is the result of a review undertaken by the National Space Council. The revisions clarify, strengthen, and streamline selected aspects of the policy. Areas affected include civil and commercial remote sensing, space transportation, space debris, federal subsidies of commercial space activities, and Space Station Freedom.

Overall, the President's newly-issued national space policy revalidates the ongoing direction of U.S. space efforts and provides a broad policy framework to guide future U.S. space activities.

The policy reaffirms the nation's commitment to the exploration and use of space in support of our national well being. United States leadership in space continues to be a fundamental objective guiding U.S. space activities. The policy recognizes that leadership requires United States preeminence in key areas of space activity critical to achieving our national security, scientific, technical, economic, and foreign policy goals. The policy also retains the long-term goal of expanding human presence and activity beyond Earth orbit into the Solar System. This goal provides the overall policy framework for the President's human space exploration initiative, announced July 20, 1989, in which the President called for completing Space Station Freedom, returning permanently to the Moon, and exploration of the planet Mars.

These and other aspects of U.S. national space policy are contained in the attached document entitled "National Space Policy."

Attachment

November 2, 1989

NATIONAL SPACE POLICY

INTRODUCTION

This document contains national policy, guidelines, and implementing actions with respect to the conduct of United States space programs and related activities.

United States space activities are conducted by three separate and distinct sectors: two strongly interacting governmental sectors (Civil and National Security) and a separate, non-governmental Commercial Sector. Close coordination, cooperation, and technology and information exchange will be maintained among these sectors to avoid unnecessary duplication and promote attainment of United States space goals.

GOALS AND PRINCIPLES

A fundamental objective guiding United States space activities has been, and continues to be, space leadership. Leadership in an increasingly competitive international environment does not require United States preeminence in all areas and disciplines of space enterprise. It does require United States preeminence in the key areas of space activity critical to achieving our national security, scientific, technical, economic, and foreign policy goals.

- The overall goals of United States space activities are: (1) to strengthen the security of the United States; (2) to obtain scientific, technological and ecomonic benefits for the general population and to improve the quality of life on Earth through space-related activities; (3) to encourage continuing United States private-sector investment in space and related activities; (4) to promote international cooperative activities taking into account United States national security, foreign policy, scientific, and economic interests; (5) to cooperate with other nations in maintaining the freedom of space for all activities that enhance the security and welfare of mankind; and, as a long-range goal, (6) to expand human presence and activity beyond Earth orbit into the solar system.

- United States space activities shall be conducted in accordance with the following principles:

  – The United States is committed to the exploration and use of outer space by all nations for peaceful purposes and for the benefit of all mankind. "Peaceful purposes" allow for activities in pursuit of national security goals.

  – The United States will pursue activities in space in support of its inherent right of self-defense and its defense commitments to its allies.

– The United States rejects any claims to sovereignty by any nation over outer space or celestial bodies, or any portion thereof, and rejects any limitations on the fundamental right of sovereign nations to acquire data from space.

– The United States considers the space systems of any nation to be national property with the right of passage through and operations in space without interference. Purposeful interference with space systems shall be viewed as an infringement on sovereign rights.

– The United States shall encourage and not preclude the commercial use and exploitation of space technologies and systems for national economic benefit. These commercial activities must be consistent with national security interests, and international and domestic legal obligations.

– The United States will, as a matter of policy, pursue its commercial space objectives without the use of direct Federal subsidies.

– The United States shall encourage other countries to engage in free and fair trade in commercial space goods and services.

– The United States will conduct international cooperative space-related activities that are expected to achieve sufficient scientific, political, economic, or national security benefits for the nation. The United States will seek mutually beneficial international participation in space and space-related programs.

CIVIL SPACE POLICY

- The United States civil space sector activities shall contribute significantly to enhancing the Nation's science, technology, economy, pride, sense of well-being and direction, as well as United States world prestige and leadership. Civil sector activities shall comprise a balanced strategy of research, development, operations, and technology for science, exploration, and appropriate applications.

- The objectives of the United States civil space activities shall be (1) to expand knowledge of the Earth, its environment, the solar system, and the universe; (2) to create new opportunities for use of the space environment through the conduct of appropriate research and experimentation in advanced technology and systems; (3) to develop space technology for civil applications and, wherever appropriate, make such technology available to the commercial sector; (4) to preserve the United States preeminence in critical aspects of space science, applications, technology, and manned space flight; (5) to establish a permanently manned presence in space; and (6) to engage in international cooperative efforts that further United States overall space goals.

COMMERCIAL SPACE POLICY

The United States government shall not preclude or deter the continuing development of a separate non-governmental Commercial Space Sector. Expanding private sector investment in space by the market-driven Commercial Sector generates economic benefits for the Nation and supports governmental Space Sectors with an increasing range of space goods and services. Governmental Space Sectors shall purchase commercially available space goods and services to the fullest extent feasible and shall not conduct activities with potential commercial applications that preclude or deter Commercial Sector space activities except for national security or public safety reasons. Commercial Sector space activities shall be supervised or regulated only to the extent required by law, national security, international obligations, and public safety.

NATIONAL SECURITY SPACE POLICY

The United States will conduct those activities in space that are necessary to national defense. Space activities will contribute to national security objectives by (1) deterring, or if necessary, defending against enemy attack; (2) assuring that forces of hostile nations cannot prevent our own use of space; (3) negating, if necessary, hostile space systems; and (4) enhancing operations of United States and Allied forces. Consistent with treaty obligations, the national security space program shall support such functions as command and control, communications, navigation, environmental monitoring, warning, surveillance, and force application (including research and development programs which support these functions).

INTER-SECTOR POLICIES

This section contains policies applicable to, and binding on, the national security and civil space sectors.

- The United States Government will maintain and coordinate separate national security and civil operational space systems where differing needs of the sectors dictate.

- Survivability and endurance of national security space systems, including all necessary system elements, will be pursued commensurate with the planned use in crisis and conflict, with the threat, and with the availability of other assets to perform the mission.

- Government sectors shall encourage to the maximum extent feasible, the development and use of United States private sector space capabilities.

- A continuing capability to remotely sense the Earth from space is important to the achievement of United States space goals. To ensure that the necessary capability exists, the United States government will: (a) ensure the continuity of LANDSAT-type remote sensing data; (b) discuss remote sensing issues and activities with foreign governments operating or regulating the private operation of remote sensing systems; (c) continue government research and development for future advanced remote sensing technologies or systems; and (d) encourage the development of commercial systems, which image the Earth from space, competitive with, or superior to, foreign-operated civil or commercial systems.

- Assured access to space, sufficient to achieve all United States space goals, is a key element of national space policy. United States space transportation systems must provide a balanced, robust, and flexible capability with sufficient resiliency to allow continued operations despite failures in any single system. The United States government will continue research and development on component technologies in support of future transportation systems. The goals of United States space transportation policy are: (1) to achieve and maintain safe and reliable access to, transportation in, and return from, space; (2) to exploit the unique attributes of manned and unmanned launch and recovery systems; (3) to encourage to the maximum extent feasible, the development and use of United States private sector space transportation capabilities; and (4) to reduce the costs of space transportation and related services.

- Communications advancements are critical to all United States space sectors. To ensure necessary capabilities exist, the United States government will continue research and development efforts for future advanced space communications technologies.

- The United States will consider and, as appropriate, formulate policy positions on arms control measures governing activities in space, and will conclude agreements on such measures only if they are equitable, effectively verifiable, and enhance the security of the United States and our allies.

- All space sectors will seek to minimize the creation of space debris. Design and operations of space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements and cost effectiveness. The United States government will encourage other space-faring nations to adopt policies and practices aimed at debris minimization.

IMPLEMENTING PROCEDURES

Normal interagency procedures will be employed wherever possible to coordinate the policies enunciated in this directive.

Executive Order No. 12675 established the National Space Council to provide a coordinated process for developing a national space policy and strategy and for monitoring its implementation.

The Vice President serves as the Chairman of the Council, and as the President's principal advisor on national space policy and strategy. Other members of the Council are the Secretaries of State, Treasury, Defense, Commerce, and Transportation; the Chief of Staff to the President, the Director of the Office of Management and Budget, the Assistant to the President for National Security Affairs, the Assistant to the President for Science and Technology, the Director of Central Intelligence, and the Administrator of the National Aeronautics and Space Administration. The Chairman, from time to time, invites the Chairman of the Joint Chiefs of Staff, the heads of executive agencies and other senior officials to participate in meetings of the Council.

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POLICY GUIDELINES AND IMPLEMENTING ACTIONS

The following Policy Guidelines and Implementing Actions provide a framework through which the policies in this directive shall be carried out. Agencies will use these sections as guidance on priorities, including preparation, review, and execution of budgets for space activities, within the overall resource and policy guidance provided by the President. Affected Government agencies shall ensure that their current policies are consistent with this directive and, where necessary, shall establish policies to implement these practices.

CIVIL SPACE SECTOR GUIDELINES

- Introduction. In conjunction with other agencies: NASA will continue the lead role within the Federal Government for advancing space science, exploration, and appropriate applications through the conduct of activities for research, technology, development and related operations; National Oceanic and Atmospheric Administration will gather data, conduct research, and make predictions about the Earth's environment; DOT will license and promote commercial launch operations which support civil sector operations.

- Space Science. NASA, with the collaboration of other appropriate agencies, will conduct a balanced program to support scientific research, exploration, and experimentation to expand understanding of: (1) astrophysical phenomena and the origin and evolution of the universe; (2) the Earth, its environment and its dynamic relationship with the Sun; (3) the origin and evolution of the solar system; (4) fundamental physical, chemical, and biological processes; (5) the effects of the space environment on human beings; and (6) the factors governing the origin and spread of life in the universe.

- Space Exploration. In order to investigate phenomena and objects both within and beyond the solar system, NASA will conduct a balanced program of manned and unmanned exploration.

  – Human Exploration. To implement the long-range goal of expanding human presence and activity beyond Earth orbit into the solar system, NASA will continue the systematic development of technologies necessary to enable and support a range of future manned missions. This technology program (Pathfinder) will be oriented toward a Presidential decision on a focused program of manned exploration of the solar system.

  – Unmanned Exploration. NASA will continue to pursue a program of unmanned exploration where such exploration can most efficiently and effectively satisfy national space objectives by among other things: achieving scientific objectives where human presence is undesirable or unnecessary; exploring realms where the risks or costs of life support are unacceptable; and providing data vital to support future manned missions.

- Permanent Manned Presence. NASA will develop the Space Station to achieve permanently manned operational capability by the mid-1990s. Space Station Freedom will: (1) Contribute to United States preeminence in critical aspects of manned spaceflight; (2) provide support and stability to scientific and technological investigations; (3) provide early benefits, particularly in the materials and life sciences; (4) promote private sector experimentation preparatory to independent commercial activity; (5) allow evolution in keeping with the needs of Station users and the long-term goals of the United States; (6) provide opportunities for commercial sector participation; and (7) contribute to the longer term goal of expanding human presence and activity beyond Earth orbit into the solar system.

- Manned Spaceflight Preeminence. Approved programs such as efforts to improve and safely operate the Space Transportation System (STS) and to develop, deploy, and use the Space Station, are intended to ensure United States preeminence in critical aspects of manned spaceflight.

- Space Applications. NASA and other agencies will pursue the identification and development of appropriate applications flowing from their activities. Agencies will seek to promote private sector development and implementation of applications.

  – Such applications will create new capabilities, or improve the quality or efficiency of continuing activities, including long-term scientific observations.

  – NASA will seek to ensure its capability to conduct selected critical missions through an appropriate mix of assured access to space, on-orbit sparing, advanced automation techniques, redundancy, and other suitable measures.

  – Agencies may enter cooperative research and development agreements on space applications with firms seeking to advance the relevant state-of-the-art consistent with United States Government space objectives.

  – Management of Federal civil operational remote sensing is the responsibility of the Department of Commerce. The Department of Commerce will: (a) consolidate Federal needs for civil operational remote sensing products to be met either by the private sector or the Federal government; (b) identify needed civil operational system research and development objectives; and (c) in coordination with other departments or agencies, provide for the regulation of private sector operational remote sensing systems.

- Civil Government Space Transportation. The unique Space Transportation System (STS) capability to provide manned access to space will be exploited in those areas that offer the greatest national return, including contributing to United States preeminence in critical aspects of manned spaceflight. The STS fleet will maintain the Nation's capability and will be used to support critical programs requiring manned presence and other unique STS capabilities. In support of national space transportation goals, NASA will establish sustainable STS flight rates to provide for planning and budgeting of Government space programs. NASA will pursue appropriate enhancements to STS operational capabilities, upper stages, and systems for deploying, servicing, and retrieving spacecraft as national and user requirements are defined.

- International Cooperation. The United States will foster increased international cooperation in civil space activities by seeking mutually beneficial international participation in civil space and space-related programs. The National Space Council shall be responsible for oversight of civil space cooperation with the Soviet Union. No such cooperative activity shall be initiated until an appropriate interagency review has been completed. United States cooperation in international civil space activities will:

  – United States participation in international space ventures, whether public or private, must be consistent with United States technology transfer laws, regulations, Executive Orders and presidential directives.

  – Support the public, nondiscriminatory direct readout of data from Federal civil systems to foreign ground stations and the provision of data to foreign users under specified conditions.

  – Be conducted in such a way as to protect the commercial value of intellectual property developed with Federal support. Such cooperation will not preclude or deter commercial space activities by the United States private sector, except as required by national security or public safety.

COMMERCIAL SPACE SECTOR GUIDELINES

- NASA and the Departments of Commerce, Defense, and Transportation will work cooperatively to develop and implement specific measures to foster the growth of private sector commercial use of space. A high-level focus for commercial space issues has been created through establishment of the National Space Council.

- To stimulate private sector investment, ownership, and operation of space assets, the United States Government will facilitate private sector access to appropriate U.S. space-related hardware and facilities, and encourage the private sector to undertake commercial space ventures. Governmental Space Sectors shall:

  – Utilize commercially available goods and services to the fullest extent feasible, and avoid actions that may preclude or deter commercial space sector activities except as required by national security or public safety. A space good or service is "commercially available" if it is currently offered commercially, or if it could be supplied commercially in response to a government service procurement request. "Feasible" means that such goods or services meet mission requirements in a cost-effective manner.

  – Enter into appropriate cooperative agreements to encourage and advance private sector basic research, development, and operations while protecting the commercial value of the intellectual property developed;

  – Provide for the use of appropriate Government facilities on a reimbursable basis;

  – Identify, and eliminate or propose for elimination, applicable portions of United States laws and regulations that unnecessarily impede commercial space sector activities;

– Encourage free and fair trade in commercial space activities. Consistent with the goals, principles, and policies set forth in this directive, the United States Trade Representative will conduct, or, as appropriate, negotiate with other countries to encourage free and fair trade in commercial space activities. In entering into space-related technology development and transfer agreements with other countries, Executive Departments and agencies will take into consideration whether such countries practice and encourage free and fair trade in commercial space activities.

– Provide for the timely transfer of Government-developed space technology to the private sector in such a manner as to protect its commercial value, consistent with national security.

– Price Government-provided goods and services consistent with OMB Circular A-25.

NATIONAL SECURITY SPACE SECTOR GUIDELINES

- General:

– The Department of Defense (DOD) will develop, operate, and maintain an assured mission capability through an appropriate mix of robust satellite control, assured access to space, on-orbit sparing, proliferation, reconstruction or other means.

– The national security space program, including dissemination of data, shall be conducted in accordance with Executive Orders and applicable directives for the protection of national security information and commensurate with both the missions performed and the security measures necessary to protect related space activities.

– DOD will ensure that the national security space program incorporates the support requirements of the Strategic Defense Initiative.

- Space Support:

– The national security space sector may use both manned and unmanned launch systems as determined by specific mission requirements. Payloads will be distributed among launch systems and launch sites to minimize the impact of loss of any single launch system or launch site on mission performance. The DOD will procure unmanned launch vehicles or services and maintain launch capability on both the East and West coasts. DOD will also continue to enhance the robustness of its satellite control capability through an appropriate mix of satellite autonomy and survivable command and control, processing, and data dissemination systems.

– DOD will study concepts and technologies which would support future contingency launch capabilities.

- Force Enhancement:

– The national security space sector will develop, operate, and maintain space systems and develop plans and architectures to meet the requirements of operational land, sea, and air forces through all levels of conflict commensurate with their intended use.

- Space Control:

– The DOD will develop, operate, and maintain enduring space systems to ensure its freedom of action in space. This requires an integrated combination of antisatellite, survivability, and surveillance capabilities.

– Antisatellite (ASAT) Capability. The United States will develop and deploy a comprehensive capability with programs as required and with initial operations capability at the earliest possible date.

– DOD space programs will pursue a survivability enhancement program with long-term planning for future requirements. The DOD must provide for the survivability of selected, critical national security space assets (including associated terrestrial components) to a degree commensurate with the value and utility of the support they provide to national-level decision functions, and military operational forces across the spectrum of conflict.

– The United States will develop and maintain an integrated attack warning, notification, verification, and contingency reaction capability which can effectively detect and react to threats to United States space systems.

- Force Application. The DOD will, consistent with treaty obligations, conduct research, development, and planning to be prepared to acquire and deploy space systems should national security conditions dictate.

INTER-SECTOR GUIDELINES

The following paragraphs identify selected, high priority cross-sector efforts and responsibilities to implement plans supporting major United States space policy objectives:

- Space Transportation Guidelines.

– The United States national space transportation capability will be based on a mix of vehicles, consisting of the Space Transportation System (STS), unmanned launch vehicles (ULVs), and in-space transportation systems. The elements of this mix will be defined to support the mission needs of national security and civil government sectors of United States space activities in the most cost effective manner.

– As determined by specific mission requirements, national security space sector will use the STS and ULVs. In coordination with NASA, the DOD will assure the Shuttle's utility to national defense and will integrate missions into the Shuttle system. Launch priority will be provided for national security missions as implemented by NASA-DOD agreements. Launches necessary to preserve and protect human life in space shall have the highest priority except in times of national security emergency.

– The STS will continue to be managed and operated in an institutional arrangement consistent with the current NASA/DOD Memorandum of Understanding. Responsibility will remain in NASA for operational control of the STS for civil missions, and in the DOD for operational control of the STS for national security missions. Mission management is the responsibility of the mission agency.

– United States commercial launch operations are an integral element of a robust national space launch capability. NASA will not maintain an expendable launch vehicle (ELV) adjunct to the STS. NASA will provide launch services for commercial and foreign payloads only where those payloads must be man-tended, require the unique capabilities of the STS, or it is determined that launching the payloads on the STS is important for national security or foreign policy purposes. Commercial and foreign payloads will not be launched on government owned or operated ELV systems except for national security or foreign policy reasons.

– Civil Government agencies will encourage, to the maximum extent feasible, a domestic commercial launch industry by contracting for necessary ELV launch services directly from the private sector or with DOD.

– NASA and the DOD will continue to cooperate in the development and use of military and civil space transportation systems and avoid unnecessary duplication of activities. They will pursue new launch and launch support concepts aimed at improving cost-effectiveness, responsiveness, capability, reliability, availability, maintainability, and flexibility. Such cooperation between the national security and civil sectors will ensure efficient and effective use of national resources.

- Guidelines for the Federal Encouragement of Commercial Unmanned Launch Vehicles (ULVs):

– The United States Government fully endorses and will facilitate the commercialization of United States unmanned launch vehicles (ULVs).

– The Department of Transportation (DOT) is the lead agency within the Federal Government for developing, coordinating, and articulating Federal policy and regulatory guidance pertaining to United States commercial launch activities in consultation with DOD, State, NASA, and other concerned agencies. All Executive departments and agencies shall assist the DOT in carrying out its responsibilities, as set forth in the Commercial Space Launch Act and Executive Order 12465.

– The United States Government encourages the use of its launch and launch-related facilities for United States commercial launch operations.

– The United States Government will have priority use of government facilities and support services to meet national security and critical mission requirements. The United States Government will make all reasonable efforts to minimize impacts on commercial operations.

– The United States Government will not subsidize the commercialization of ULVs, but will price the use of its facilities, equipment, and services with the goal of encouraging viable commercial ULV activities in accordance with the Commercial Space Launch Act.

– The United States Government will encourage free market competition within the United States private sector. The United States Government will provide equitable treatment for all commercial launch operators for the sale or lease of Government equipment and facilities consistent with its economic, foreign policy, and national security interests.

– NASA and DOD, for those unclassified and releasable capabilities for which they have responsibility, shall, to the maximum extent feasible:

— Use best efforts to provide commercial launch firms with access, on a reimbursable basis, to national launch and launch-related facilities, equipment, tooling, and services to support commercial launch operations;

— Develop, in consultation with the DOT, contractual arrangements covering access by commercial launch firms to national launch an launch-related property and services they request in support of their operations;

— Provide technical advice and assistance to commercial launch firms on a reimbursable basis, consistent with the pricing guidelines herein; and

— Conduct, in coordination with DOT, appropriate environmental analyses necessary to ensure that commercial launch operations conducted at Federal launch facilities are in compliance with the National Environmental Policy Act.

- Government ULV Pricing Guidelines. The price charged for the use of United States Government facilities, equipment, and services, will be based on the following principles:

– Price all services (including those associated with production and launch of commercial ULVs) based on the direct costs incurred by the United States Government. Reimbursement shall be credited to the appropriation from which the cost of providing such property or service was paid.

– The United States Government will not seek to recover ULV design and development costs or investments associated with any existing facilities or new facilities required to meet United States Government needs to which the U.S. Government retains title;

– Tooling, equipment, and residual ULV hardware on hand at the completion of the United States Government's program will be priced on a basis that is in the best overall interest of the United States Government, taking into consideration that these sales will not constitute a subsidy to the private sector operator.

- Commercial Launch Firm Requirements. Commercial launch firms shall:

– Maintain all facilities and equipment leased from the United States Government to a level of readiness and repair specified by the United States Government;

– ULV operators shall comply with all requirements of the Commercial Space Launch Act, all regulations issued under the Act, and all terms, conditions or restrictions of any license issued or transferred by the Secretary of Transportation under the Act.

- Technology Transfer Guidelines.

– The United States will work to stem the flow of advanced western space technology to unauthorized destinations. Executive departments and agencies will be fully responsible for protecting against adverse technology transfer in the conduct of their programs.

– Sales of United States space hardware, software, and related technologies for use in foreign space projects will be consistent with relevant international and bilateral agreements and arrangements.

- Space Infrastructure. All Sectors shall recognize the importance of appropriate investments in the facilities and human resources necessary to support United States space objectives and maintain investments that are consistent with such objectives. The National Space Council will conduct a feasibility study of alternate methods for encouraging private sector investment, including capital funding, of United States space infrastructure such as ground facilities, launcher developments, and orbital assembly and test facilities.

- The primary forum for negotiations on nuclear and space arms is the Nuclear and Space Talks (NST) with the Soviet Union in Geneva. The instructions to the United States Delegation will be consistent with this National Space Policy directive, established legal obligations, and additional guidance by the President. The United States will continue to consult with its Allies on these negotiations and ensure that any resulting agreements enhance the security of the United States and its Allies. Any discussions on arms control relating to activities in space in forums other than NST must be consistent with, and subordinate to, the foregoing activities and objectives.

White House Fact Sheet on the Commercial Space Launch Policy
September 5, 1990

POLICY FINDINGS

A commercial space launch industry can provide many benefits to the U.S. including indirect benefits to U.S. national security.

The long-term goal of the United States is a free and fair market in which U.S. industry can compete. To achieve this, a set of coordinated actions is needed for dealing with international competition in launch goods and services in a manner that is consistent with our nonproliferation and technology transfer objectives. These actions must address both the short term (actions which will affect competitiveness over approximately the next 10 years) and those which will have their principal effect in the longer term (i.e., after approximately the year 2000).

- In the near term, this includes trade agreements and enforcement of those agreements to limit unfair competition. It also includes the continued use of U.S.-manufactured launch vehicles for launching U.S. Government satellites.
- For the longer term, the United States should take actions to encourage technical improvements to reduce the cost and increase the reliability of U.S. space launch vehicles.

IMPLEMENTING ACTIONS

U.S. Government satellites will be launched on U.S.-manufactured launch vehicles unless specifically exempted by the President.

Consistent with guidelines to be developed by the National Space Council, U.S. Government agencies will actively consider commercial space launch needs and factor them into their decisions on improvements in launch infrastructure and launch vehicles aimed at reducing cost and increasing responsiveness and reliability of space launch vehicles.

The U.S. Government will enter into negotiations to achieve agreement with the European Space Agency (ESA), ESA member states, and others as appropriate, which defines principles of free and fair trade.

Nonmarket launch providers of space launch goods and services create a special case because of the absence of market-oriented pricing and cost structures. To deal with their entry into the market there needs to be a transition period during which special conditions may be required.

There also must be an effective means of enforcing international agreements related to space launch goods and services.

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